DDT and the Insect Problem

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II

PREFACE

THIS IS only the first installment of the story of DDT, but its publication at this time seems necessary because of the tremendous interest in the subject, the amount of misinformation current about it, and the need for correlating what we know as a starting point for further progress.

As Brigadier General James S. Simmons phrased it, "DDT is one of the most wonderful things, medically speaking, to come out of the war, but it must be used with intelligence and judgment." It is the hope of the authors that this volume will contribute something to that end.

Substantiating Brigadier General Simmons' opinion is that of the American Association of Economic Entomologists, which, in a statement issued Dec. 15, 1944, expressed itself in these words:

"We feel that never in the history of entomology has a chemical been discovered that offers such promise to mankind for relief from his insect problems as DDT. There are limitations and qualifications, however. Subject to these, this promise covers three chief fields: Public health, household comfort, and agriculture.

"As public health we include control of the insects which carry diseases that have scourged humanity, such as malaria, typhus, and yellow fever. Household comfort is taken to cover such things as flies, fleas, bedbugs, and mosquitoes.

Agriculture includes not only farms, gardens, and orchards, but forests, livestock, and poultry."

The available data are not so detailed as we would like, for the scientific method is slow as well as thorough. Nevertheless, the astonishing amount of research so far achieved leaves us deeply indebted to the hundreds of men responsible: the chemists and entomologists of the government services, the malaria-control units of Army and Navy, the farmers who offered their crops for testing, the workers of many state agricultural experiment stations, and the chemists of industry. In our list we include also Maurice B. Frank of Chicago, whose interest in the subject and recognition of the need for a single compendium of information on DDT led to the compilation of this book.

It is not a scientifically complete summary of the literature on DDT for the research worker. It is rather a summary prepared with the needs of the user in mind, and emphasis herein stems from that objective. Thus, the chemistry has been reduced to a highly simplified description, while the pharmacology and toxicology are rather fully reviewed; and the formulation, the manufacturers' problem, is briefly explained, while many details are given regarding the mixing of formulations for actual use.

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Chapter I

INTRODUCTION

DDT is one of the many valuable things we have salvaged from the waste left by war on a thousand battlefields. It helped tremendously in achieving victory. All we need do now is learn to use it properly to make it equally valuable in peace.

DDT is an insecticide. It kills "bugs" of all sorts. In fact it seems destined already to take a place as the best weapon yet discovered in man's ages-long war with a hitherto unconquerable enemy, the insects. It is not a panacea; it will not kill all insects but it will kill more of them than anything else so far known. It has been rather badly presented to the public as a "miracle" insect killer and entangled with all the sentimental appeal naturally clinging to something that saved soldiers' lives and health and hastened the day of victory. That is perhaps why the public may expect too much of it now. It will undoubtedly do a great deal, but it is not a miracle; it is a chemical fact. It will kill not only insects but other cold-blooded and warm-blooded forms of life, because it is a powerful chemical. The only element of the story that smacks of the miraculous is the fact that it came along just when we needed it—and badly—to help win the war.

DDT, as compared with most other insecticides, has two outstanding characteristics. In the first place its insecticidal effect lasts a long time; properly applied it stays in place and kills for as long as several months (in some cases). Entomologists call this the "residual" effect of DDT. Most other insecticides wash off, evaporate, or change chemically so that their effect is comparatively shorter. In the second place it has a "two-way action." To understand that, it is necessary to recall that there are two kinds of insect pests: those which chew plant foliage and those which instead puncture it with a beak and suck out its juices. The chewing insects will succumb to a stomach poison, something they ingest with the vegetation they eat. The sucking insects require a contact poison, something that will kill them when it hits any part. DDT's two-way action means that it works against both types; it kills when eaten and it kills insects that merely walk on it. A third important factor, though not so exclusive, is the fact that it is an extremely powerful poison; minute doses kill. From the earliest tests made, while it was under study only as a military weapon for lice and mosquitoes, for instance, it was known that a minimum concentration of 10 mg. per square foot was effective, *i.e.*, about as much as the point of a sharp pencil. (Standard dosages are set higher, however.)

But the triple combination explains why the talk about a miracle insecticide began and why DDT struck the insect world with an effect perhaps comparable to the atomic bomb on human beings. It explains, too, why American DDT production, which jumped from nothing to 3,000,000 lb. a month in less than 2 years, is being maintained at a high level though the military's demands are dropping steadily. And it explains why, in the relatively short time since the

Army and Navy began to release it to civilians in substantial quantities, its value against so many insects has been established. The research effort poured into DDT is on the scale of the $2,000,000,000 expended on the atomic bomb. Actually, we have learned more about DDT in 3 years than any entomologist would have expected to establish about a new insecticide in a decade, at the normal pace of research.

We know now that it will kill practically all the insects, such as mosquitoes, flies, and lice, that plague man and his animals and that it will kill very many of the agriculturally important insects. But we are only beginning to envision its potentialities, as imagination begins to build on the foundation of fact presented to us by the laboratory men. It can also be sprayed from an airplane, and that means clearing forests of the insect plagues that destroy them. Perhaps the same technic can be applied to cities under municipal sponsorship, thus relieving man of the necessity for screens and fly swatters. There are plans to include it in paints, soap powders, floor waxes, and other articles. There are, however, a number of important insects against which DDT has not so far been shown to be effective, but it works well against the very large majority of important insects.

Still, we need to know a great deal more about it, especially about how to use it to get full effectiveness. As will be realized in the following pages, almost every possible proportion and form of DDT appears in the research reports, *e.g.*, emulsions, suspensions, and solutions in percentages ranging from microscopic to huge. An immediate need is for some standardization of dosage for the various purposes and a standard form of reporting dosages. So far every research worker has figured out his own formulation and reported it

differently, with the result that it is sometimes impossible to determine the amount of DDT that reached and killed the bug. It is also clear that, because of the lack of preliminary instruction as to dosages, much of the research work employed needlessly high amounts. Standardization would make comprehension and interpretation of research work simpler and also enable it to be tested in the field and forest, where DDT must eventually meet its supreme and decisive tests. It is becoming clearer that a very few commercially simple formulas will serve, and all the research effort possible should be brought to bear on such formulas to permit the most rapid general utilization of DDT that can be achieved.

For, until all possible information regarding DDT has been gathered and distributed, we shall not be able to use it to its full potential. To use an insecticide intelligently we must know which insects yield to it and which resist it. How small a dose will kill which insect? In what form shall it be administered—dusts, aerosols, solutions, or suspensions? What does it cost? What will it do to beneficial insects, such as bees, the unique pollinators of many crops, and those which in nature prey on harmful species? What plants will it hurt? Will it poison the soil as the arsenicals do? How does it compare in cost, effectiveness, ease of handling, and toxicity with well-established, time-tried insecticides? Is it good for field crops? For truck gardens? For orchards? Against insects of the forest and the tree and shrub nurseries? What about insects that attack man himself and his domestic animals? Will it injure the hosts as well as their insect parasites? Does it hurt wild life, the birds and fishes and small mammals of the forest areas? Which formulation is best and when? What percentage of

DDT should it carry? Will it mix with other insecticides and fertilizers?

Thanks to dozens of chemists and entomologists and other workers in various government services, who almost alone have had control of DDT since it was brought to this country, many of these questions can be answered definitely now, as will be seen. A surprising amount of information valuable in the peacetime usage of DDT has been accumulated, despite the basic military motivation of the work done with it up to 1945. There is much more to come, from the laboratories and test plots of the U.S. Department of Agriculture, from the U.S. Department of the Interior, from the state agricultural experiment stations, and from private laboratories all over the country. Within another "bug year," too, a great deal of "clinical experience" will have been recorded as a check against the planned and controlled work of the research men.

But the material already available fairly well outlines the useful area to be served by DDT. We know definitely that it is a good insecticide and that it is safe for man to use. Against most insects it is the best we have. There are some drawbacks, but they do not seem so serious as when they were first pointed out and should not interfere with a most intensive effort to bring DDT into full use.

It should be observed, as we pass on to the discussion of various phases of DDT, that most of the objections to it apply as well to other insecticides. DDT's drawbacks are not peculiar to it, and its valuable peculiarities, as will be seen, make it possible to eliminate some of the objections, notably in the case of bees.

Soil Poison. Does DDT poison the soil? Probably not, when used against foliage insects as a spray or dust. Whether or not it is injurious when large amounts are worked into the soil against grubs of the Japanese beetle, for instance, is a question that only time and study can answer satisfactorily. In one test [1] * radishes grown in soil containing 250 lb. of DDT per acre, thoroughly washed and then fed to young larvae of the white-fringed beetle, were not poisonous. It has also been mixed with bean and carrot seed at planting, for protection against symphylids,[2] without damage, as far as the report indicated.

At the same time [3] a government report, summing up unchecked observations from various workers, said that DDT in the soil at the rate of 25 lb. per acre was

> . . . found to retard the growth of bush beans, lima beans, soybeans, hollyhock, onions, spinach, tomatoes, strawberry plants and rye. . . . In most instances, however, it would take several years to accumulate injurious amounts of the chemical in the soil from applications and dosages that would be used normally on crops for control of insect pests. The rate of decomposition in the soil has not yet been determined.

It should also be noted that reports of hundreds of applications of DDT made no mention of soil toxicity or effect on plants and that other insecticides remain in use despite their known deleterious effect on plants. It is more important to kill the insects and have a plant left than to retard its growth a little.

As far as direct injurious effect of sprays or dusts on plants is concerned, DDT seems dangerous only with respect to the

* Superscript numbers refer to the bibliography at the end of each chapter.

gourd family, which is discussed later. In another government report [4] this observation is made:

> No exhaustive tests have been conducted on the tolerance of plants to DDT dust or spray mixtures or solutions. However, the work that has been done with DDT dusts indicates that tomatoes, potatoes, cabbage, turnips, onions, beans, peas and tobacco are tolerant to low strengths and reasonable dosages of this material and that some injury to squash or other cucurbits may be expected when this material is applied in dust form at low concentrations.

It should also be made clear that many of the solvents used for DDT are poisonous to plants (kerosene, fuel oil, xylene, and the like) and that some of the unfavorable results may be traced to them rather than to the DDT. It is quite likely that dusts or water suspensions containing a minimum of solvent will be the principal agricultural formulations, to the exclusion of solutions.

In another government report [8] this opinion was expressed:

> Most of the trees and plants on which DDT has been used have not shown evidence of injury. On some apple trees, however, there has been some yellowing and dropping of foliage, but an increase in mite abundance has been largely, if not wholly, responsible.
>
> In experiments with soil treatments for Japanese beetle grubs, 26 pounds of DDT per acre definitely retarded the growth of bush beans, lima beans, soybeans, hollyhock, onions, spinach and tomatoes. Some of the bean leaves became yellow and tomato plants were somewhat distorted. Higher strengths cause some growth retardation in beets, carrots, muskmelons and potatoes.
>
> Tests are under way at Beltsville (Md.) in which excessive quantities of DDT have been applied to the soil under apple

and peach trees, to simulate the accumulation that might occur over a period of years if DDT should come into general use. Thus far no injury has become evident.

A federal government report [12] indicated that DDT used as a 5 per cent dust on sugar-beet and onion fields did not adversely affect the germination rates of the pollen from the two crops.

Beneficial Insects. DDT, like other insecticides, kills beneficial as well as harmful insects. There are many of these—the bees, wasps, and flies that pollinate many of our most important crops, the flies and larvae that serve as food for birds and fish and as bait for fishermen, others that serve to improve the soil or as scavengers, and those which destroy other insects as predators or parasites. Most important of all probably are the predators, the parasites, and the bees. DDT can kill all of them. In some instances it is not effective against harmful insects, such as orchard mites, but kills the predators that destroy them, such as lady beetles. However, the situation is not so serious as it appears to be at first glance; the same thing is true of other insecticides and yet they continue to be used.

Among predators, insects that kill and eat others, the principal ones are the coccinellids or lady beetles; the chrysopids or lacewings, the larvae of which are known as aphis lions; the dragonflies; the carabids or ground beetles; the syrphids or flower flies. Several of these have already appeared in the literature of DDT.[1, 9, 10] A Wisconsin report [6] on a series of cage tests showed that the two-spotted lady beetle (*Adalia bipunctata*), one of a dozen lady beetles of importance as predators, is "quite readily killed by walking over

surfaces sprayed with a water suspension of DDT." The lady beetle is a well-known devourer of spiders and aphids, and the observation has several times been made that those pests increased after a DDT spray. The same report detailed similar results with a syrphid fly, undesignated. A single Texas observation [6] suggested that a 3 per cent dust on eggplant killed various chrysopids and permitted nymphs of *Trileurodes abutilonea* (a leaf-feeding white fly) to thrive.

Another note on this subject says: [8]

> General observations have indicated that DDT is very toxic to many forms of insect life and that its application to fruit trees brings down a tremendous number of beneficial insects. Cage tests have shown that DDT is extremely toxic to many hymenopterous parasites, including *Macrocentrus ancylivorus* of the oriental fruit moth and *Pseudaphycus* sp. of the Comstock mealy bug. There are also numerous indications that DDT is fatal to many of the lady beetles that normally control aphids, mealy bugs and mites.

So far there have been no definitive reports on other predators, or on such parasites as *Ascogaster carpocapsae* Vier. and *Trichogramma minutum* Riley, which attack the codling moth; or parasites of aphids such as *Aphelinus mali* Hald. There is no denying the tremendous amount of benefit done for mankind by these predators, though they often wait until the damage has been done before they get to work, and it may be that DDT will have to prove good enough to clean up all insects, to make the predators unnecessary. Other insecticides are known to kill them, but it appears in previous cases that the adults were always able to avoid the spray in flight and thus repopulate the area. DDT's long-lasting effect, however, enables it to kill them on their return, and

it thus presents a somewhat different problem, as yet unsolved. The only suggestion made so far is the combination of an aphicide with the DDT, so that the predators become unneeded.

The honeybees and their wild cousins, the bumblebees, are the most important insect pollinating agents. Their importance to agriculture cannot be overemphasized. There are at least 49 crops [7] that would produce little or no fruit or seed without their aid; *e.g.*, apple, apricot, avocado, cherry, cucumber, grape, peach, pear, plum, strawberry, alfalfa, all the cabbage family, carrot, clover, cotton, all the gourd family, onion, soybean, radish, turnip, and vetch among seed crops. Even where fruit or seed is not the edible portion of the plant, setting of seed must occur if there is to be a crop the following year.

Bees have suffered seriously in recent years. The war made it worse, for bees and beekeeping were not considered essential, by shortsightedness or snap judgments among those responsible. Bad farming practices such as planting competitive crops near by (bees will not go to alfalfa, for instance, when sweet clover is available), forest fires, large concentrated plantings of single unattractive crops, the automobile, and paved roads have all played a part in the destruction of bees. But one of the most important factors is the use of insecticides. Paris green and some others will kill bees, but the worst of all, to beekeepers, are the arsenates, which the bees take back to the hive, thus poisoning the whole colony. The topic is so important that several court suits are now reported in progress to determine the responsibility of farmers who kill neighbors' bees with insecticides applied to their

own crops. So much insecticide has been used in some orchards that the arsenic settling down has poisoned the soil and forced its abandonment.

DDT will kill bees, too, at least in cages. But government experts, when questioned, admit that it does not seem to do so in the field. Testing is still going on and will probably continue for some years to come, but for some reason the investigators have not yet found the expected kill of bees from DDT. That, to bee experts, is extremely good news.

Probably an important factor in the situation is the timing of the application of DDT. Bees ordinarily fly to a blossom, dip into it, and then fly to another; only a sick bee crawls around on foliage. Thus if the DDT application is made before the blossoms open, the fresh clean tissue of the open blossom, free of poison, greets the bee when it finally arrives, and the insect is not killed. The pollen, which the bee takes back to the hive as food for young, also remains free of poison. So, too, does the honey.

"If it is carefully done," said one government man in discussing this phase of the DDT problem, "I believe that DDT will not be so bad as arsenic."

If pollen and honey are clear of poison, the danger of wiping out whole colonies, as happens with arsenic, would also be eliminated. Tests are being made on this point.

Several of the reports made to the U.S. Department of Agriculture and published by it during 1945 indicated that special attention was paid to the problem of the bees. In no case so far recorded has the use of DDT in any form agriculturally brought any kill of bees. One report [1] summed it up with reference to an experiment on Lygus bugs on alfalfa in Utah:

The DDT (a 10% dust) was applied during the pre-bloom stage, after the buds had formed but before many flowers had opened, in order to avoid killing wild bees essential to pollination. No domestic bees were present in the area.

So far as could be observed, the DDT had no repellent effect on, and caused no mortality of, the wild bees. The experiment indicated the possibility that DDT can be used without appreciable harm to domestic or wild bees, provided application during the main blooming period is avoided, but further observations are necessary for the settlement of this question.

Large aphid and thrips populations in the treated plots were virtually eliminated. Other insects, such as the coccinellid beetles and larvae, nabid nymphs and adults, grasshoppers, flies and lepidopterous larvae, were killed. The highly migratory species constantly reinfested the plots, but their numbers were usually less in DDT-treated than in untreated plots, indicating that this insecticide has a lasting residual effect.

NEGATIVE RESULTS IN TESTS WITH DDT. In a certain number of cases, DDT has failed to give effective control, according to the majority of reports. The U.S. Department of Agriculture, in a summary dated Mar. 20, 1945, listed 14 destructive pests against which DDT was found to "have little or no effect." This list included these insects: cotton-boll weevil, cotton aphid, cotton-leaf worm, California red scale (adult), Florida red scale, parlatoria scale, Mexican bean beetle, orchard mites (two kinds), sugar-cane aphid, sugar-cane borer, red spider, plum curculio, cattle grubs.

In addition there are varying reports as to its effectiveness against other aphids; in some tests DDT produced good results, in others, poor. Furthermore, the numerous reports of experimental work published by the U.S. Department of Agri-

culture include several other insects against which DDT was not particularly effective or as good as previously known insecticides, though in most cases only one test effort was made. These reports include the Lima-bean-pod borer, a mealy bug (*Pseudococcus mauritimus*) on *Taxus*, the cabbage-seed-pod weevil (*Ceutorhynchus assimilis* Payk.), the sweet-potato weevil (*Cylas formicarius elegantulus* Summers), the tobacco hornworm, two wireworms (*Limonius californicus* Mann. and *L. canus* Lec.), and the pepper maggot.

Aphids. There are a few reports indicating that DDT is effective against aphids, or plant lice. Various Geigy papers (the Swiss Geigy Company has the patent on DDT) insist that DDT gives "excellent control." However, the majority of U.S. Department of Agriculture observations is even more insistent, not only that DDT does not kill most aphids, but also that it does kill predators and thus permits aphids to increase on treated foliage. This is also true of arsenates and other insecticides. The reports are so nearly unanimous, however, that it can probably be accepted at present, always allowing for the possibilities of future experimentation, that DDT is almost useless against aphids. The answer, of course, since DDT is so generally effective against other insect pests, is to combine DDT with an aphicide and thus clear the crop of both types of pest.

Mites. Something similar occurs in the case of mites. The common red spider (*Tetranychus* spp.) is often mentioned as increasing in areas treated with DDT, while the DDT itself seems to kill only a small percentage, whether applied as dust, spray, or aerosol.

Mexican Bean Beetle (*Epilachna varivestis* Muls.). Numerous efforts have also been made to work out a method of

utilizing DDT'S killing power against this common pest, but the reports are unanimous that it is ineffective, as compared with rotenone or cryolite.

THE BALANCE OF NATURE. FISH, BIRDS, MAMMALS. Back in the early days of experimentation with DDT it was applied on the surface of one of two neighboring ponds in Tennessee as part of a test against mosquito larvae. It killed the larvae successfully, but it also killed the fish in the pond. Moreover —and surprisingly—fish in the other pond died. Perhaps the first reaction to that event was the basis for the miracle tag DDT acquired, but, if it was, the mystery was soon dispelled. The local ducks were to blame. They were picking up enough of the DDT from the surface of the treated pond and carrying it to the other to kill the fish in the second. It was not a serious mishap, but it opened up a new line of investigation— the danger DDT carried for wild life.

The Army has not been interested in that phase. The military purpose was to kill mosquitoes and lice, to protect the lives of soldiers and keep them on the fighting line, no matter what happened to the fish, the Japs, the birds, or any other accidental victim. The Army could—and did—practically sterilize with airplane-dispersed DDT solutions various combat areas, such as certain Pacific islands, so that some of the fly-bitten, mosquito-ridden coral specks were entirely free of insects for long periods.

But that entirely understandable attitude will not do for peace uses on valuable agricultural, forest, or recreation areas. Not only might it destroy their value, but it might also upset the balance of nature and thus open the way to permanent harm. The balance of nature here refers to the natural economic setup involving the closely interwoven food supplies of

various animals, the insects themselves, fish, birds, mammals, the pollination function of the bees, the scavenger function of certain species, and related elements. Of course other insecticides applied on the same scale as DDT by airplane will similarly interfere with the natural organization of the particular area, but it has to be worked out with respect to DDT.

When it was shown by laboratory tests that as little as 0.1 part per million in water will kill all the goldfish in a tank, the experimenters realized that fish are peculiarly susceptible to DDT. Later tests in the field confirmed this. For instance, DDT was sprayed by airplane at the rate of 0.5 lb. per acre on a 5-mile strip of Island Beach on the eastern side of Barnegat Bay, N.J., to control mosquitoes. It cleaned up the insects successfully, but the next few tides washed up some 75,000 dead fish on the shore—menhaden, mullet, killies, and other shore fish largely, according to the U.S. Fish and Wild Life Service. Still later fishermen reported dead, dying, or paralyzed crabs in the bay, though most of the crabs had simply disappeared. In another case DDT was applied from an airplane at the rate of 0.3 lb. per acre to Wallop's Island, Chincoteague Bay, Va., with a similar effect on the fish. Further studies showed that tadpoles, crayfish, frogs, salamanders, snakes, turtles, and many water insects are easily killed by DDT. The film of oil on the surface also kills aquatic life coming up to breathe. Moreover, it was shown that part of the poison eventually sinks and kills some of the bottom organisms. These results have been confirmed several times in planned experiments.

A series of laboratory tests [11] with DDT in Lake Erie water showed that DDT is toxic to *Daphnia*, the microscopic freshwater shellfish which serve as food for small fish. Since the

small fish are in turn a principal food of larger, economically important fish like bass, the observation may be significant. Using various concentrations of a 1 per cent solution of DDT in acetone, the author reported:

> It was found, in all but one instance, that 50 per cent of the *Daphnia* were immobilized by concentrations of over one part per billion in thirty-two hours or less. Concentrations from one to one hundred parts per billion immobilized the animals in periods between sixteen and thirty-two hours. Animals in concentrations of less than one part per billion survived as long as the controls in Lake Erie water alone. Some experiments were run as long as 130 hours.

It has also been established that birds may be killed by eating DDT-killed insects. However, rats and mice in nature do not seem to be affected unless exceptionally large amounts of DDT are applied. A large-scale test was carried out near Scranton, Pa., where sections of a forest area were sprayed from an airplane at rates of 1, 2, and 5 lb. per acre. Birds were found dead or dying only where the 5-lb. dosage was used, but the 2-lb. dose killed fish. Low dosages, down to 0.1 and 0.2 lb. per acre, caused no discoverable mortality in fish. Water insects killed by the DDT when used as a mosquito larvicide included whirligig beetles, water boatmen, back swimmers, damsel-fly (dragonfly) nymphs, fly larvae, particularly nonbiting gnats. A 5 per cent DDT emulsion in xylene, applied by airplane at the rate of 2 qt. per acre, on water 4 in. deep, caused bloodworms to leave their tunnels and die in 3 or 4 hr. "In no instance," the U.S. Department of Agriculture reported, however, "have any injurious effects of application of DDT for killing mosquito larvae been observed on warm-blooded animals."

Actually, as far as many observers will commit themselves at the present stage of the investigation, great concern over the disturbance of the balance of nature does not seem to be justified. The concentrations to be used, definitely valuable against the insects aimed at, will eventually be set at a low level, much below the 5 lb. per acre reported to have killed Pennsylvania's birds. If the birds disappear it is more likely to be because their food supply—insects—has been killed off. Moreover, areas in which the animal population has been driven out with DDT tend to fill up again rather soon.

The foregoing pages should have made it clear that DDT is here to stay. What follows will, it is believed, make it equally clear that DDT will soon be recognized as our principal insecticide because of its prolonged action and two-way toxicity, because it is effective against so many different insects, and because of the saving in time, money, and effort those virtues make possible.

The reader will see, as the story unfolds, that the experimental results still vary rather widely. That is explainable by the differences in mixtures and types of mixtures used, variations in the isomer content of the product going into the mixtures, and sometimes no doubt by the attitudes of the individual investigator. The trend, however, is fairly clear, and in the chapter on formulations an effort is made to clarify the situation further.

But the variation emphasizes the need for pressing all available resources into service to get the final answers to all our questions.

There is no doubt that leaders who are insisting on the importance of continued intensive research into DDT are amply justified. DDT controls too many insects of great

significance to man to allow it to be neglected now, and it is unthinkable that Congress or any state agency charged with responsibility in this field would let it happen by failing to make all necessary appropriations and plans. Give them money and facilities, and the chemists and entomologists of the nation will turn out a finished piece of work.

It is not certain, either, whether DDT as we know it now will be the form on which final preference will settle. The sulfa drugs (DDT to certain bacteria) were introduced in the form of sulfanilamide nearly a decade ago. Since then, however, they have gone through a dozen forms that were made public and thousands that were tested and dropped, until now the most common form is sulfadiazine. The chemists are as busy with DDT now as they were with the sulfonamides, seeking to improve the molecule. Several variant forms have already appeared, though none has yet proved as good as DDT itself.

The British have produced a chemical known as gammexane (the gamma isomer of benzene hexachloride) or 666, which is apparently a good insecticide similar to DDT, but it is easily destroyed by alkalies, making it unusable in hard water, has a bad odor, and is irritating to the eyes, nose, and skin. However, the next try may be more successful.

TDE (or 1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethane) has recently been reported [13] as having toxicity equal to or greater than that of DDT against larvae of *Anopheles quadrimaculatus* Say in preliminary laboratory tests. In fuel-oil solutions it "appears to be definitely more toxic to anopheline larvae than DDT."

In University of California tests, reported by Science Service, DD (or dichloropropane dichloropropylene) was reported ef-

fective in destroying wireworms when applied to the soil at 400 lb. to the acre 1 to 3 weeks before the crop is planted.

Many new formulations of DDT are also to be expected. Various proposals have been advanced already to include it in paint, soap, and floor waxes. The use of DDT in a soap as a flea and louse insecticide seems most hopeful of all proposals so far, though a good deal of study will be necessary to perfect it. It would be easier to spray a painted wall to kill flies than to paint it, however.

Our biggest problem as far as DDT is concerned, then, to sum up the whole picture, is to find out how to get the most use from it. Study and research alone can solve it.

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Chapter II

INSECTS AND INSECTICIDES

INSECTS are probably man's worst enemy, with the possible exception of himself, yet man could hardly get along without them.

THE HARM INSECTS DO. Insects deprive man of food by eating his crops or killing in some way the plant life on which he is dependent for nourishment. They destroy his home, his books, his clothing, his furniture. They annoy him and his domestic animals by crawling, biting, or stinking. They tear down the things he builds. They transmit disease that often kills. They outnumber and outweigh him at all times and not infrequently they outsmart him.

"The struggle between man and insects began long before the dawn of civilization, has continued without cessation to the present time and will continue, no doubt, as long as the human race endures," two entomologists [1] expressed it.

Then they drew an indictment of insects. (1) Insects injure all kinds of growing crops and other valuable plants by chewing some part of the plant, by sucking the sap, by boring into some part, by attacking roots, by laying eggs in some part, by building nests or shelter in plants, by establishing other

insects in plants, or by carrying fungous, bacterial, virus, or protozoan disease to plants. (2) They attack and annoy man and other living animals by flying about or crawling over them, by sucking blood, by biting them, by laying eggs in or on their bodies, by living in or on their bodies as parasites, by their repulsive odors or the disagreeable tastes of their bodies or secretions, by the decomposition of their bodies, by injecting or applying venoms by stingers, mouth parts, or nettling hairs or through the mouth with food or on the skin, and by carrying disease to man or his animals or harboring infections that eventually pass to man. (3) They damage or destroy stored foods or other possessions of man by devouring them, contaminating them, building in them, or increasing the labor of handling them or preparing them for use.

Insects cover the whole earth in incredible numbers. Technically an insect is a member of the phylum Arthropoda in the animal kingdom and of the class Hexapoda. Hexapoda are six-legged animals, and the name insect should properly be restricted to them, though in common usage it also includes spiders, mites, ticks, and other eight-legged creatures which are members of phylum Arthropoda but of class Arachnida. (DDT will kill many spiders but seems to be less effective against mites and ticks.)

However, it is when we look into the books—for no man has a mind big enough to encompass the whole picture—that we begin to realize the terror of Hexapoda. It is the largest classification of animal. Nearly 700,000 species have been described and named and entomologists say there may be 10,000,000. One author computed that, while the total human population of the world is 2,145,000,000, there are at

least that many insects on every square mile of the land surface of the earth,[2] except deserts and polar areas, and another 5,000,000 flying about in the air above each square mile. It seems hard to believe, for most of us are conscious of insects only when they bite, like mosquitoes, or crawl on a bald spot, like a fly, but the few figures available tend to bear it out. Counts made by curious entomologists have indicated various frequencies of 1,000,000, 3,500,000, and more than 10,000,000 individual insects per acre. One investigator studying insects in the forest soil of Illinois found an average frequency down to a depth of 18 in. of 65,000,000 per acre. The most common and familiar illustration is the sight of a brood of grasshoppers such as from time to time descends on American farms, stripping everything in sight and leaving nothing but devastation behind.

Another measure of the damage done by insects, tentative and highly qualified as it must be, is contained in a U.S. Department of Agriculture report [3] on the character and financial measure of the losses caused by insects, mites, and ticks in this country.

> The estimated damage done by the insects included in this paper is $1,601,527,000 annually. Much of this loss is preventable and warrants continued efforts to discover more effective control measures and to secure more effective application of the control measures already known.

The underlying figures of the report are equally astonishing: $145,525,000 per year for mosquitoes, including the cost of control measures and losses due to malaria; $121,283,000 for the cotton-boll weevil, which uncontrolled has damaged practically one-third of the crop in various localities; $98,-

268,000 for the corn-ear worm, which also attacks tomato and cotton plants; $66,450,000 for the housefly; $65,680,000 for the codling moth; $18,500,000 for the Colorado potato beetle; $300,350,000 for losses due to insect damage to stored cereals; $100,000,000 in forest trees for various insects; $87,-000,000 in shade trees; $85,000,000 for poultry pests; $42,000,-000 for greenhouse insects; $40,000,000 for wireworms; $35,-000,000 for ambrosia beetles and other forest-products pests; $25,700,000 for grasshoppers; $22,000,000 for clothes moths, and so on.

Beneficial Insects. On the other hand, without the aid of the pollination function of the bees and a few other insects, man would not have many of his most important crops, as was pointed out in the preceding chapter. But there are many other services performed on behalf of man by insects. The bees produce honey and beeswax, for a total estimated [1] at $16,000,000 and $2,100,000 respectively. The whole silk industry, not so important now since the advent of nylon and other synthetic fibers and further affected by the war, rests on the activity of the silkworm, a moth larva. Shellac, cochineal dye, and other chemical or medical substances also enter the picture. Insects also supply an estimated two-fifths of the food of fresh-water fishes and one-third of the food of wild songbirds and game birds. They destroy weeds as well as valuable plants. They aerate the soil and fertilize it, serve as scavengers of plant and animal debris, converting it into plant food, and do other minor chores.

Probably second only to their pollination function, as far as service to mankind goes, however, is their cannibalistic work in keeping down the numbers of hostile insects. The lady beetles and the aphids, the dragonflies and mosquitoes,

the ground beetles and the gypsy-moth larvae are just a few examples of an incredible activity in that direction. These are all predatory insects, attacking and eating other insects. In addition there are the insect parasites, a few flies and a number of small wasps, which live on or in other insects, often laying their eggs on them in flight. The larvae hatched from eggs glued to the surface of the victims eat their way inside, destroying the insect. That phase of insect service was summed up by a minor nineteenth-century writer, Augustus De Morgan, who is now best remembered for the usually misquoted lines:

Great fleas have little fleas upon their backs to bite 'em,
And little fleas have lesser fleas and so ad infinitum.
And the great fleas themselves in turn have greater fleas to go on;
While these again have greater still, and greater still, and so on.

So, hateful as insects may seem to be when they destroy something valuable, there is also a good deal to be said in their favor. But their services do not relieve us of the task of striving to reduce the loss caused by the harmful ones.

Insect-control Measures. There are many ways in which insects are restrained from overwhelming the earth through their astronomical rates of reproduction. Among the natural methods are the predatory and parasitic insects just referred to; birds, which in summer often subsist almost entirely on insects; a number of small mammals, such as moles, shrews, and skunks, which are also largely dependent on insect food; and various snakes, salamanders, newts, and

toads (which can devour in 24 hr. about four times their stomach capacity). Soil conditions, the temperature range, available moisture, and rainfall also affect the number of insects in any given region.

Crop rotations to deprive insects of favored foods, soil operations, removal of food supplies or breeding places such as manure heaps, the planting of insect-resistant varieties of crops, physical methods such as the draining of swamps where mosquitoes breed, and the use of traps are among the minor control methods applied by man.

But in the war with insects our principal reliance is on insecticides. Before DDT entered the scene there were a dozen or more stomach poisons (for use against chewing insects) and as many contact poisons (for use against sucking insects) currently used in this country.[1] In the first group were arsenate of lead, calcium arsenate, Paris green, zinc arsenite, magnesium arsenate, crude arsenious oxide, white arsenic, London purple, sodium fluoride, fluosilicates, and hellebore. They vary widely in their characteristics, but all except hellebore burn foliage in greater or lesser degree. Principal reliance probably was placed on the lead and calcium arsenates for general use; they cost moderately, adhere well to foliage, and are rated low in foliage-burning power. They are used as dusts, sprays, and in baits.

Among the contact poisons are nicotine in some form, pyrethrum, rotenone, kerosene and other oils, lime-sulfur mixtures, thiocyanates, sodium or barium sulfide, and various soap preparations. Uses vary widely, the oils and lime-sulfur being applied as dormant sprays (while the plant is dormant), the soaps, nicotine, rotenone, pyrethrum, and kerosene as general sprays or dusts. Their tendency to damage foliage

is not so great, but some, such as nicotine and pyrethrum, are expensive.

A third type of insecticide is the fumigant, materials that form a gas fatal to insects. These include hydrocyanic gas, carbon bisulfide, nicotine, sulfur dioxide, napthalene, paradichlorobenzene, carbon tetrachloride, and some others.

Many of them are highly poisonous, the arsenates, nicotine, thallium sulfate, and practically all the gases especially. Some are inflammable, dangerous to plants as well as insects, and of limited utility.

DDT measures up ideally when contrasted with the available insecticides. It is cheap, comparatively speaking, easily mixed for use, less poisonous than most when used with proper precautions, noninflammable except in certain solvents, and effective against both chewing and sucking types of insects. It is also usable in some fields now served by fumigants. Further increase of its value is certain.

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Chapter III

CHEMISTRY AND PHARMACOLOGY OF DDT

What Is DDT?

FROM the standpoint of the ordinary citizen, unlearned in chemistry, the man who coined the term "DDT" was a benefactor of humanity. Otherwise John Q. Citizen, wanting just to kill a few bugs, would be asking his druggist for it by any of several long and difficult technical names. Of course the chemical names are scientifically precise and correct, but even that realization would be of little help if he had to say, "A little 2,2-bis(parachlorophenyl)-1,1,1-trichloroethane, please," or the less specific "dichlorodiphenyltrichloroethane," or even the practically slang "chlorinated diphenylethane." DDT, based on the underlined letters in the second name quoted, is indeed much easier to say. (Incidentally, it should be "DDT" without periods.)

It is, however, not too painful a task to understand the build-up of the DDT molecule, and for those who are interested we will include a simplified description of it. (Others are welcome to skip the next few paragraphs.)

It begins with ethane, a colorless, odorless, inflammable gas that is extracted from natural gas or Pennsylvania petroleum, one of the aliphatic hydrocarbons used in various chemical processes and as a fuel and as a refrigerant. Ethane consists of 2 atoms of carbon (C) and 6 atoms of hydrogen (H), all linked together like this:

$$\begin{array}{ccccc} & & \mathrm{H} & & \\ & & | & & \\ \mathrm{H} & — & \mathrm{C} & — & \mathrm{H} \\ & & | & & \\ \mathrm{H} & — & \mathrm{C} & — & \mathrm{H} \\ & & | & & \\ & & \mathrm{H} & & \end{array}$$

The ethane molecule, C_2H_6

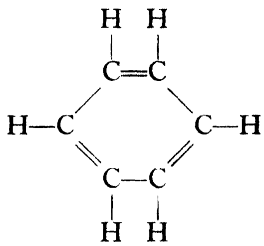
Now, if a chlorine (Cl) atom is substituted for each of the three hydrogen atoms attached to the lower carbon atom of the ethane molecule and an oxygen (O) atom added to each of the two hydrogen atoms on either side of the upper carbon atom, the molecule looks like this:

$$\begin{array}{ccccc} & & \mathrm{H} & & \\ & & | & & \\ \mathrm{OH} & — & \mathrm{C} & — & \mathrm{OH} \\ & & | & & \\ \mathrm{Cl} & — & \mathrm{C} & — & \mathrm{Cl} \\ & & | & & \\ & & \mathrm{Cl} & & \end{array}$$

The chloral hydrate molecule, $CCl_3CH(OH)_2$

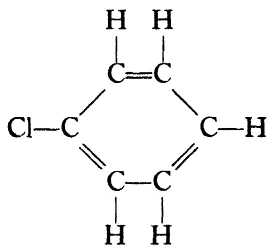
This version is known to the chemist as trichloroacetic aldehyde, to the druggist as chloral hydrate, and to the night clubs as "knockout drops." It forms, as we shall see, the spine of the DDT molecule, though the changes to be made will eliminate all its sleep-producing properties.

For the two "wings" of the DDT molecule—both the same—we also begin with a petroleum fraction, the important one known as benzene. Benzene consists of six carbon and six hydrogen atoms linked together in a ring, like this:



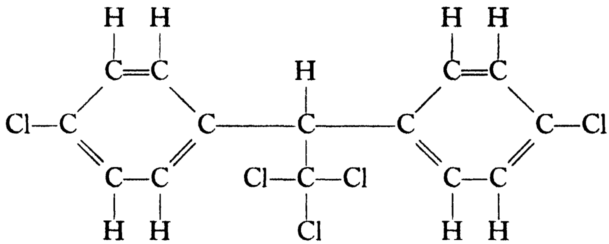
The benzene ring, C_6H_6

If one of the outer hydrogen atoms is knocked off the benzene ring (also called the "phenyl group") and a chlorine atom substituted, the result is monochlorobenzene, and the molecule looks like this:



Monochlorobenzene, C_6H_5Cl

By linking a monochlorobenzene molecule to either side of the chloral hydrate molecule in place of the two OH groups attached to the upper carbon atom, we get DDT. The extra hydrogen atoms of the benzene rings are also dropped out. The result looks like this—and the various atoms must be attached in just this way or the whole thing doesn't count:



The DDT molecule, $(p\text{-}ClC_6H_4)_2CHCCl_3$

DDT is manufactured by mixing monochlorobenzene and chloral hydrate in the presence of sulfuric acid. The sulfuric acid and the miscellaneous atomic debris left over are washed out with water. The result is a white waxy-looking powder, with a mild, not unpleasant, odor, called DDT—technical grade. Actually, in the process not all the chlorobenzene molecules have attached themselves in just the right places, and the technical grade consists of somewhere between 70 and 80 per cent of pure, perfect DDT molecules.. The imperfectly formed molecules are called (more or less accurately) isomers.

An improved method of manufacture involves the mixture of metathetical quantities of chloral hydrate, chlorobenzene, and chlorosulfonic acid, eliminating the dehydration of chloral hydrate and the use of sulfuric acid in large quantities. Simpler and with a higher yield efficiency, it opened the way to better purification and establishment of the correct melting point at 110 deg. centigrade.

The isomers, which are almost useless as far as insect killing goes, can be separated by extracting the pure DDT with alcohol recrystallization, as is done to get the DDT for use in aerosol bombs. Ignorant or conscienceless insecticide makers have sold the residue, the DDT isomers, in solutions to unwise customers. The solution sold probably contains

some other insecticide for a quick kill, but it could not offer any of DDT's outstanding advantages and is disappointing, to say the least.

For practical purposes, however, it is not necessary to go to the trouble of sorting out the pure DDT molecules from their isomers. The insecticide manufacturer, as he plans his formula, need only know just what percentage of pure DDT there is in the specific material he is using and count only that in mixing his product. In that way, he will get the right proportion of active DDT into his mixture to do the job his label claims it will do, regardless of what isomers may also be present.

Half a dozen or more tests for the presence of DDT have been devised as an essential step in the long task of studying it. They are largely based on the presence of chlorine, since the 5 chlorine atoms, because of their greater atomic weight as compared with the 14 carbon and 9 hydrogen atoms, make up more than half the total mass of the DDT molecule. Most of the tests are rather complicated.

DDT is regarded as being fairly stable; *i.e.*, it does not decompose and lose its strength quickly. The worst enemies of DDT so far found are certain metallic salts, such as ferric chloride. In the presence of this material a hydrogen and a chlorine atom leave their bonds in the DDT molecule and get together to form hydrochloric acid, leaving the remainder of the DDT molecule practically inert. Aluminum and chromium chlorides will act in the same way. Certain solvents, such as orthoparadichlorobenzene, make DDT more susceptible to this deterioration. Others are reported as inhibiting it.[1] Certain materials, strongly alkaline, will also destroy it. Other weakening factors are exposure as residue

of sprays to sunlight—which must be kept in mind in its use in open fields—and high temperatures.

However, other reports indicate that it may resist sunlight in certain solutions, such as alcohol. It evaporates only very slowly, and exposure to air does not weaken it. But one of its most valuable properties, the key to its long-lasting effect, is that it does not dissolve in water beyond about 1 part per million, an insignificant amount. It dissolves only in fats and oils and various commercial solvents. This insolubility in water complicates the task of preparing it for use.

Is DDT Dangerous?

DDT is a slow-acting poison that, if given in sufficient amounts or over a long enough period of time, can kill most living things all the way up the animal scale to man. Nevertheless, all that we have been able to learn about it so far indicates that there is no particular danger to human beings in its use as an insecticide, if it is handled with proper precautions.[2]

Human Beings. As far as man himself is concerned, chemists who have studied the toxicology of DDT estimate that it would take 5 to 10 g. of it to provide a fatal dose for an adult; with such a lightweight powder as DDT, that would be about a handful, though it represents only about ⅕ oz. One to five milligrams could cause symptoms of poisoning.

A group of scientists at the National Institute of Health of the U.S. Public Health Service, Bethesda, Md., reported that they had exposed two men, one aged forty-two years, the other fifty-four, to air saturated with DDT from aerosol bombs at the rate of 1 g. per 1,000 cu. ft. of air for 1 hr. a day for 6

days. Careful studies of the two subjects, before and after the test, brought this verdict: no toxic effects.[2]

Two other groups, one of three men, the other of four, all laboratory workers who had been exposed for several months to DDT mists and dusting powders, have also been studied.[3] Two of the first three had had "extremely great" exposure for 3½ months, the third had been working with DDT for 9 months. The verdict in the first group was "none of them presented definite findings that can be attributed to the toxic action of DDT." The second group had been working with a DDT aerosol smoke generator in field tests. The verdict after careful studies of blood, urine, liver, and other functions was "no definite evidence of DDT toxicity in these individuals."

Studies have also been made of persons whose work exposes them to DDT,[3] and the verdict has been the same. Another U.S. Public Health Service scientist said that ½ g. of DDT swallowed had produced no ill effects.

An English laboratory worker reported a case of DDT poisoning[4] in which a chemist with his bare hands kneaded 25 g. of DDT in inert dust in an acetone solution for a considerable time. He developed symptoms that left him indisposed for 10 weeks and not fully recovered for a year. A second case has been found in the United States, but details are not yet available. No death has occurred here from DDT poisoning, and, aside from the two cases just referred to, there have been no cases of poisoning, despite several wild rumors. In Rockford, Ill., for instance, a man walked into a room which had recently been sprayed with DDT and collapsed; his case was at first reported as DDT poisoning

Investigation showed that he was a victim of duodenal ulcer, which had perforated and produced hemorrhage and collapse, and that his symptoms were in no way related to DDT.

The only death so far proven to be due to DDT poisoning is that of a nineteen-month-old Negro child[16] at a British base in West Africa who drank about 1 oz. of a 5 per cent kerosene solution. Symptoms began in 10 minutes with coughing and vomiting, for which neighbors gave him palm oil. More than 2 hr. later, in collapse, he was taken to an army hospital, where he died about 4 hr. after drinking the poison. Autopsy showed death was caused by pulmonary edema. The liver was congested, the spleen twice the normal size, and the brain edematous. The fatal dose was computed at 150 mg. per kilogram of body weight. Tests comparing DDT and kerosene, done on baboons, showed that the autopsy findings were the effect of the DDT. Two bull terriers suffering from skin infections were sprayed with the solution and died 2 months later of injury to liver and kidneys from the DDT.

The same journal told of tests[17] on two volunteers who remained 48 hr. in a steel chamber, the inside of which was coated with a 2 per cent DDT paint, over which a film of lubricating oil was spread. Careful observation showed that contact of the naked skin of their backs with the DDT and oil produced "definite toxic effects," including numerous changes in blood chemistry and the appearance of indoxyl sulfate in the urine; together with heaviness of limbs, severe pains in joints, sight impairment, muscular tremors and weakness, and patchy anesthesia, indicating nerve involvement. Return to normal took 26 to 33 days.

A Chinese report [18] of skin patch tests of DDT oil solutions as high as 20 per cent demonstrated a reduction of skin sensitivity to touch, but not to pain, cold, or heat.

Summing up available facts and the opinions of scientific workers, the prediction seems warranted at this time that we shall have no cases of DDT poisoning from insecticidal use unless negligence or malice has led to disregard of the proper precautions. The dose required to do damage is too high and the possibility of getting it normally is too slight.

PRECAUTIONS. DDT can be taken into the body in dangerous amounts in various ways—aside from the intentional. Mists and sprays, either oil or water, can be inhaled. Dusts can be inhaled. Oil solutions can be absorbed through the skin. It can be ingested with food contaminated by either dusts or sprays. It can also be taken by mouth by mistake for food, such as flour. Water suspensions, however, by reason of their low absorbability, are less dangerous on the skin, and dry DDT dust on the skin is entirely safe, as millions who have used it as a louse powder can testify.

For the ordinary householder or gardener, using it occasionally to kill house or garden insects, probably no elaborate precautions are necessary against DDT poisoning. Even if he breathes in some of the mist or dust he is not likely to get enough to do any harm from a few minutes' use; if his work with it is prolonged, especially inside a building, a gauze mask or handkerchief across his nose and mouth will give enough protection and make him feel safer. Soap and water and a brush should be used to remove immediately any oil solution from his hands and face.

The health-department worker, the farmer using it on his crops and livestock, and the factory worker employed in a

DDT plant present a different problem. In their cases the length of time during which they are exposed (if prolonged) might raise a real danger, especially from solutions. Rubber gloves and other protective clothing, respirators, ventilating equipment, and careful removal of residues on the skin, however, should protect them. Human beings can stand far more of the chemical than they are exposed to in using it properly as an insecticide but must guard against its cumulative action.[8] Such workers should also be subjected to regular urine examinations, for reasons to be described below, to determine whether they are absorbing any substantial quantity. It is difficult to establish any more specific rules for such cases; a study of the individual situation should be made by an expert in doubtful cases.

The question of DDT residues on fruits and vegetables to be eaten without peeling has not yet been finally answered. The U.S. Department of Agriculture has set a tentative rule of not more than 7 parts per million as a safety limit, pending detailed study. A number of investigations made in California and published in a single report[14] will give some idea of the situation.

Perhaps the most significant is a comparison made of two groups of Bartlett pear trees, one sprayed with a 0.1 per cent water suspension from 20 per cent wettable powder, the other with a 0.1 per cent emulsion from an oil solution. Two sprayings with the suspension gave 0.5, 2.1, and 2.7 parts per million in three tests; one group sprayed four times gave 3.7 parts per million. The oil emulsions gave 1.7, 2.3, 3.6, and 6.1 parts per million. Analyses were made from 1 to 2 months after the spraying.

Analyses of onions sprayed twice with a DDT emulsion (0.125 per cent) at the rate of about 2.5 lb. per acre showed 11.58 parts per million on the tops, 3.72 parts per million on the topped onions, 46.90 parts per million on the outer layer of the topped onions, and none on the peeled bulbs. "Judging from this series of analyses," the report concluded, "no residue problem is involved, provided the onions are peeled before use."

Studies of DDT-treated peas showed that DDT remained on the pods but not on the kernels. An alfalfa field treated twice with a 3 per cent dust at the rate of 28 lb. per acre showed 29 parts per million 4 weeks later. Tomatoes sprayed two to four times in August with a 0.25 per cent suspension showed 8 parts per million on small green fruit ½ in. in diameter and not over 0.5 parts per million on ripe 50-g. fruit in November. Olives sprayed with various oil emulsions showed 23 to 33 parts per million 10 weeks later.

This problem of DDT residues is one of the more important phases of DDT action yet to be investigated. It is involved not only in the treatment of agricultural products destined for human use but in that of such material as alfalfa and vetch, fed to cattle, in the protection of stored grains, and in the protection of forested areas where it might affect both insect and vegetable food of wild life. Pending an authoritative decision, efforts should be made to time spraying so that the DDT does not accumulate on fruits or vegetables destined for use as food. For instance, tomato plants should not be sprayed after they have begun to form fruits. Development of a satisfactory method of removing DDT, as is done with arsenate and other poisons, would also help. At present,

DDT's insolubility in water makes washing difficult and unsatisfactory.

The demonstration (reviewed below) that DDT fed to lactating animals appears in their milk and can poison animals consuming the milk poses another question of residues. It might conceivably be shown that, for instance, cows eating silage on which DDT had been deposited would pass it along in their milk to human subjects.

There are numerous factors operating against the possibility, however, such as the facts that DDT used in open fields is ultimately destroyed by sunlight and that the quantities cattle might get from silage would be extremely small, of which much would be naturally eliminated. It should be kept in mind that the milk demonstration came from laboratory work, in which relatively large quantities of DDT were deliberately fed to the test animals, far more than they could get under ordinary circumstances. The question should be answered as quickly as possible.[19]

There seems to be a general though unofficial agreement in the literature on DDT that a 30-day period should elapse between the last application of DDT and the harvesting of food crops. This gives ample time for weathering to destroy the toxicity of the DDT and for continuing growth of plants to reduce the proportion of DDT to the total vegetation. As a recent government statement [20] said, no case of DDT poisoning has yet appeared from an insect-control operation, and "the effect of DDT on higher animals is markedly less than that of many insecticides such as nicotine and the arsenicals."

Meanwhile certain other general precautions can be recommended, particularly for household use.

DDT, tasteless and resembling flour in its dust formulations, should never be stored near food supplies where it might be used by mistake.

Sprays, mists, or dusts should never be discharged where food is exposed, in the kitchen, in food stores, in granaries, in flour mills, or similar situations.

A final danger, associated with certain formulas, is indirect but especially important to the householder. It is that of explosion and fire. Many DDT solvents such as kerosene are inflammable, especially in the form of sprays or mists. Never use them near an open flame, including a lighted cigarette.

The foregoing should have made clear, at least so far as present knowledge permits, the slight danger involved in using DDT. There is apparently no cause for alarm, provided proper precautions are taken according to the circumstances. As a matter of fact, DDT in its various uses so far outlined is no more dangerous than many of the extremely poisonous materials hitherto used for insect control—the lead, arsenic, copper, and other materials spread thickly over fields and orchards each year and similar substances used in insect control in the home. Many workers believe it is less dangerous.

Antidotes. But suppose DDT poisoning should occur? What to do then? That question too can be answered satisfactorily through the work of the chemists, physicists, and biologists of the National Health Institute.

They noticed first that a solvent called cyclohexanone seemed to interfere with the poisonous effects of DDT on the central nervous systems of experimental animals. Cyclohexanone is a narcotic. It was also established at post-mortem examination of such test animals that signs of healing of the

nerve or liver damage caused by DDT sometimes appeared, indicating that the damage was not permanent and that tissues could be restored if the poison was stopped. This thought occurred: Why not control the convulsions with hypnotic drugs and see if the animal can survive a fatal dose? A series of experiments with rats showed that such survivals could be brought about.

Amytal sodium, phenobarbital sodium, and paraldehyde gave little help; dilantin sodium was better, but urethane (ethyl carbamate) saved 35 of 40 DDT-poisoned rats to which it was given, while 32 of 40 similarly poisoned, but untreated, controls died.[7]

Meanwhile three Brazilian workers had struck off on another path. They believed that the convulsions were due to a deficiency of calcium in the body, for calcium deficiency, as is seen in extreme cases of rickets, for instance, causes convulsions somewhat similar to those of DDT. So they gave calcium gluconate to dogs poisoned with about 50 mg. of DDT for every pound of the animal's weight. If the calcium was given before the poison, they reported, it prevented the appearance of the characteristic DDT symptoms. If given afterward it shortened their duration and enabled the animals to survive.[8] There has been some corroboration of this work.

Meanwhile, pending further studies, the recommended procedure in case of acute DDT poisoning would be

1. Call a physician.
2. Wash out the stomach thoroughly.
3. Give a saline—not an oil—laxative.
4. Give urethane, for several days if necessary, in a dosage sufficient to control the nervous symptoms.

How Does DDT Work?

Despite extensive work on both laboratory animals and insects this question is not yet completely answered.

The susceptibility of various lower animals to DDT varies widely. Studies have shown, for instance, that cold-blooded animals are more easily affected by DDT than warm-blooded ones. That is probably one of the reasons why it is such an efficient insecticide.

For insects it is both a contact poison and a stomach poison, as we have pointed out.

DDT works slowly. An insect walking across a DDT-impregnated surface or struck with a droplet from a spray may function normally for a while—even bite—but then it loses the power of coordination, begins to tremble, goes into convulsions, and finally dies. The process may last from one to several hours. The slang terms for its effects are "the DDT's" and "the gesarol jitters," the latter from a trade name for one of its formulations. A few insects are unaffected by it; some may recover from insufficient doses.

The exact mechanism by which its insecticidal effect is accomplished is not yet completely understood. There is some evidence to indicate that its affinity for fats and oils (indicated by its solubility in them) will eventually lead to the secret. Insects' hard outer shells (the chitinous exoskeleton) contain certain fatty materials that may absorb it. The tissue of which nerve sheaths are formed also contains fatty substances. The sensitive receptors of some insects' feet are nerve tissue, and that may have something to do with its effect. And apparently DDT is a "nerve poison" to insects,

as indicated by the convulsions which poisoned insects display.

Further evidence of its fat affinity has been found in studies on dogs fed DDT over long periods. Heavy deposits, relatively speaking, were found in the body fat, and more was associated with the plentiful fat of the milk of lactating dogs. When the poison was administered in oil solutions, the deposits were larger. They disappeared when the poison was stopped.[9]

DDT in the milk of lactating rats whose diet consisted of 0.1 per cent DDT was also passed on to their nursing offspring, two Ohio investigators reported.[15] The typical tremors appeared in the mother rats between the sixth and the thirteenth days and in the nurslings between the fourteenth and fifteenth days of the DDT diet. In 18 days all were dead but one of the three mothers and one of the nurslings, both of whom recovered when the DDT was stopped.

Similarly, according to the same report, nine adult rats fed milk from goats receiving daily 1 g. of DDT per 8 to 9 lb. of body weight died with DDT symptoms in from 2 to 29 days. It was noted that the longer the goats remained on the DDT diet the more toxic their milk became. The same DDT goat milk when fed to a nursing mother rat produced symptoms in her suckling offspring. The DDT apparently disappeared from the goat milk in about 48 hr., at least in toxic amounts.

A half-grown kitten died of the poisoned goat milk in 3 days, but apparently goats have a high resistance to it, for neither mother nor kids died. However, lactation ceased in the goats between the twenty-first and twenty-eighth days of DDT dosage.

The DDT was in the fat globules of the milk, for butter made from poisoned goat milk killed rats. The DDT had

to be administered by mouth to the goats. There was no toxicity in milk from goats sprayed with a 10 per cent DDT emulsion. The authors suggested further tests to determine the possible toxicity of milk or butter from cows which might ingest DDT from forage crops or by licking themselves.

There is likewise doubt as to just where the poison exerts its effect. Two U.S. Department of Agriculture workers studying cockroaches concluded that it strikes somewhere along the main shaft of any given nerve, not at its point of origin in the ventral nerve cord or its ending in the muscle.[10] Workers at the University of Pennsylvania have been unable to demonstrate any effect of DDT on test-tube cultures of embryonic nerve cells.[11] Temperature is also a factor in its effect on insects. Flies knocked down by DDT at 70 deg., for instance, recovered if moved to a temperature ranging from 80 to 100 deg., and took longer to be affected by the poison at the higher temperatures.

Fish, as cold-blooded animals, are readily affected by DDT, and the Fish and Wildlife Service of the U.S. Department of the Interior is seriously concerned over destruction of food fish by airplane spraying to control insects. DDT is also known to paralyze crabs, but not kill them, if they are moved to fresh water. On the other hand, studies are under way to determine if there is any dosage that will kill marine pests, such as oyster drills and starfish, without harming valuable fish and oysters.

DDT is also fatal to birds which chance to eat insects killed by DDT.

Generally speaking, however, the warm-blooded species can ingest and survive as much as hundreds of times the dose of DDT that kills cold-blooded types. Why is not understood;

a peculiar sidelight on this observation is that ticks engorged with the blood of warm-blooded species are almost immune to DDT. But among the warm-blooded animals so far tested, there is also a wide range of susceptibility. Young animals seem less resistant, at least among mice and rats, than adults. Mice and cats are more susceptible to DDT poisoning than most other experimental animals. In cats the effect is more persistent than in other animals such as rabbits. The symptoms in cats are different; they show more nervous symptoms and less liver damage and there is a smaller proportion of the poison found in their blood and bile, as compared with rabbits.[7] Chickens and guinea pigs on a given dosage level show fewer instances of tissue damage than other animal species.[5] Rabbits can take twice as much as rats.[6] Dogs take large amounts before they show damage.

Among larger animals, cows seem more sensitive to DDT. They developed tremors of hind legs and neck on doses of about 0.05 to 0.1 g. per pound of body weight per day for 3 weeks. Only one of three sheep similarly tested, however, showed symptoms (liver damage), while the other sheep and a horse remained unaffected.[5]

The Illinois Natural History Survey at Urbana fed DDT-dusted corn to two hogs so that the animals got 7.1 mg. per kilogram of body weight per day for 30 days. They "remained normal in behavior and gained an average of 31.5 lb. of weight each" on the 336 lb. of corn consumed, the report said.[13]

The exact action of DDT in the body is another phase of the problem not yet completely investigated. Work done at the National Institute of Health, Bethesda, Md., has made

it possible to distinguish two types of DDT poisoning, one acute, the other chronic. They vary widely in symptoms.

Acute poisoning, such as follows the ingestion of a large amount of DDT, fatal or not, within a short period of time, manifests itself largely in disturbance of the central nervous system. The symptoms resemble those seen in insects. First there is overexcitability, then failure of coordination, then tremors, then spasms, then spastic paralysis and convulsions, then flaccid or limp paralysis, and finally death from exhaustion, if the dose was large enough. It is against this type of poisoning that the use of urethane is effective, as heretofore described. Some reports have mentioned minor brain or other nerve-cell damage.

The chronic type lacks the nervous symptoms. It results from small doses given over a long period. In it the damage is concentrated largely in the liver, where cells slowly degenerate and die, with ultimately fatal results to the animal. Meanwhile, in either type of poisoning the poison can be detected in various body fluids, particularly the urine and bile. If it is given by mouth, large amounts seem to pass off unchanged in the feces, but if it is given in the form of an oil solution by mouth, the amount so disposed of is reduced. As much as one-twentieth of the total dose administered can be disposed of through the kidneys in rabbits, but the fecal or stool content may range as high as 50 per cent of the dose.[7] A single large dose will also produce a higher fecal content as compared with repeated small doses, much of the poison seeming to pass off unabsorbed. In rabbits the storage in the blood is low, but high in the bile.

In a series of cats on a small daily dosage, symptoms did not appear until the eleventh day for the earliest and the twenty-

sixth day for the latest. However, DDT was present in the urine within 5 days, long in advance of any detectable signs of poisoning. Similar work was done on rabbits and dogs.

It is on the basis of such observations that workers exposed for long periods of time to inhalation or absorption of DDT are urged to have frequent and regular checks made. Studies of urine can reveal the existence of the danger long before trouble develops.

Although some of the DDT administered to test animals may be excreted through the kidneys unchanged, some of it also undergoes transformation in the body, according to a report by two National Health Institute workers.[12] The altered molecule has been identified by x-ray-diffraction techniques as dichlorodiphenyl acetic acid, a substance that can be manufactured from DDT in the laboratory. This metabolite, as it is called, is harmless and seems to represent the body's attempt to defend itself against the malevolence of DDT.

Summary

From the foregoing it is clear that DDT is a dangerous poison in itself, something to be handled with the greatest respect.

Nevertheless its potential value, scarcely realized as yet, as an insecticide and as man's most potent weapon against his worst enemy (except himself) is so great that the effort to learn to use it safely is well worth while.

If that lesson is learned and the indicated precautions carried out, there is no substantial danger to human life and health in the use of DDT. The high dosage required to do harm to human beings, the slight chance of getting it, and

the means of checking the danger and of protecting ourselves against it are all ready at hand.

Much more study is needed, both for safety and to expand our skill and the field of utility of this new tool for better living.

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Chapter IV

HOW TO USE DDT

THE use of DDT is complicated by the fact that it is not soluble in water, which often makes it necessary to resort to various devices for getting it into a form in which it may be sprayed for killing insects. Also its melting point is so low that the heat generated in grinding its normally lumpy bulk would melt it. Thus, it must be properly handled in order to make it into a dusting powder. After those difficulties are conquered, DDT may be handled in ordinary spraying or dusting equipment, properly adjusted.

It is of course more important to the ultimate user, as contrasted to the manufacturer or formulator, to know what forms are available and to which purposes they are applicable, rather than the difficulty of mixing. But some explanations may be an aid to understanding the situation and making the right selections among the forms of DDT offered to the user. It is wasteful to use so valuable an insecticide as DDT without getting its full value.

DDT is on the market in the form of dusts ranging from 1 to 10 per cent DDT concentration, usually with the remainder made up of pyrophyllite, bentonite, talc, or some other

mineral capable of being finely ground; solutions in oil or another solvent; emulsions; and water suspensions, all in various percentages. In addition there are aerosols and paints, with soaps, waxes, and possibly other forms indicated for the future. An unofficial British report had DDT in ordinary laundry soap keeping long-haired dogs free from fleas and lice up to 9 weeks.

SOLUTIONS. DDT, insoluble in water, dissolves in a number of oils, including vegetable oils such as cottonseed, as well as fuel oil, kerosene, and various other petroleum extracts. A number of the common industrial solvents will dissolve it. (There seems to be little point in listing them here; government publications [1] on DDT and the literature of solvent manufacturers supply them in dozens.) Sometimes an auxiliary solvent, such as cyclohexanone, is used to speed the solution process.

Care must be exercised in the use of solutions. Such solvents as kerosene or fuel oil will stain textiles or certain paints and burn foliage. They are also inflammable, especially in finely dispersed mists. Some of them are poisonous and others are irritating to eyes, nose, throat, or skin. These effects are due to the solvent, not to the DDT. For that reason professional DDT users wear masks, goggles, and other protective clothing.[2] Solutions, however, being ready for use, are more convenient for domestic use on a small scale than are emulsions and suspensions, which must be mixed as used.

EMULSIONS. A second way to prepare DDT for use is to dissolve it in a suitable solvent, such as xylene, add an emulsifier, such as some of the synthetic wetting agents or detergents, and then mix the solution with water. This is the type of

preparation used in the U.S. Public Health Service antimalaria campaign. It is valuable for large-scale uses, but, despite the small proportion of solvent left in high dilutions, the solvent may damage living plants, and a suspension is preferred for application to green foliage. Several insecticide manufacturers furnish a concentrate containing usually 25 per cent of DDT. Supplied with it there should be a dilution table, showing how much water to mix with a given amount of the concentrate to make sprays of whatever percentage of DDT may be required for the task in hand. Thus 1 qt. of a 25 per cent concentrate, containing ½ pt. of DDT, mixed with 4 qt. of water, would make a 5 per cent emulsion. Using 24 qt. of water would make a 1 per cent emulsion, and 49 qt. would make a 0.5 per cent emulsion. A 1 per cent soap solution can also be used to make such emulsions.

WATER SUSPENSIONS. A third form of DDT preparation is the water suspension. This type involves the use of a solvent which dissolves in water. The DDT is first dissolved in the solvent, such as alcohol or acetone, with a wetting agent, and mixed with pyrophyllite and allowed to dry. Then it is reground as an extremely fine powder to which the DDT adheres. The powder is subsequently mixed with water to make whatever strength is required. In another form DDT, a fine-ground diluent, and a wetting agent are mixed dry. Since the DDT is thrown out of solution it must be kept agitated to keep the fine particles of DDT in suspension in the water. It is usually supplied in a 20 per cent form.

The water suspension is a valuable method of handling DDT for agricultural uses. It has few drawbacks as far as damage is concerned and can be used on livestock or foliage freely.

DUSTS. DDT, as noted previously, cannot easily be ground alone and must be mixed with some diluent, such as pyrophyllite, talc, walnut-shell flour, or bentonite for satisfactory working. It is combined in proportions up to about 10 per cent practically, though much higher concentrations are possible for special uses. Dusts are valuable in agriculture, though on foliage they lack the sticking characteristics of the aqueous formulations. They may be used on human beings or livestock in concentrations up to 10 per cent (the Army louse power) without fear of harm. Airplane distribution of dust is also proving feasible.

AEROSOLS. Aerosols are dispersions of DDT in solution in the form of particles so fine that they resemble a solution in air. It must be said, however, that experts consider them wasteful in some cases, because they do not realize to the full DDT's potential as a residual insecticide. Their purpose is to hit all insects in the area covered at once, and the residual factor is not important. Careful studies have shown that they are not toxic in insecticidal proportions.[3, 4, 5]

There are two forms. One is the DDT as it is sprayed from an airplane. Numerous devices have been constructed to break up the DDT into extremely fine particles as it leaves the plane, utilizing the propeller wash, the venturi tube, breaker fans, and other methods, and it is a satisfactory way to sterilize large areas. The Army worked it out first for use in combat areas from bombers.[6] More recently the U.S. Department of Agriculture has been applying it to the task of spraying large insect-infested forest areas.[7] Studies are also in progress as to the droplet size and its relation to effectiveness.

The second type of aerosol is the "aerosol bomb." This is a container filled with Freon liquefied under pressure and holding a purified form of DDT in solution, usually with an auxiliary solvent. When the cap is released, the gas pressure forces out a finely dispersed mist of DDT, valuable in clearing limited enclosed areas of insects. The bomb, invented by a U.S. Department of Agriculture worker a few years ago, was taken over by the Army in its antimosquito antimalaria fight early in the war. It then used pyrethrum, which gives a quick kill. Later DDT was added to the mixture to increase the killing power, and, when this device was placed on the market recently, popular demand for DDT made it a fast-moving article. However, pyrethrum will do everything the bomb can be expected to do, and the DDT should be used in other forms for its residual effect.

An interesting Arizona report [8] tells of the use of a fog generator, originally developed by the Todd Shipyards Corporation to produce opaque smoke screens from oil for Navy combat use, to disperse DDT in oil solution over large fields and on livestock. Two machines were lent, while they were still a war secret, to the University of Arizona Agricultural Experiment Station at the request of Col. Dale Bumstead for testing on his ranch at Peoria, Ariz.

The net conclusion drawn was that such a fog generator holds the possibility of being developed into an extremely effective and cheap method of distributing DDT. The first tests were made against thrips on citrus and leaf hoppers on grape and produced a high kill at points relatively close to the machine, the kill dropping slowly up to the edge of the effective range, from 300 to 350 ft.

Difficulties were encountered with wind velocity and with the effect of masses of air heated at ground level and rising to carry the fog too high for any value. The general opinion among those who witnessed the test was that adaptation of the machine to produce a heavier particle and certain other changes would make it effective. The cost was estimated at less than half ($1 per acre compared to $2.25) the cost of applying insecticide with ordinary spraying equipment.

Good results were reported for control of horn flies and stable flies on cattle and in barns, and the method was pronounced better than the accepted dipping of cattle for control of such pests.

Two entomologists who witnessed the tests concluded that [9]

> The fog best adapted to concealment (the original purpose) is too fine and light for best results in insecticide applications in the field. It billows and rises to heights far greater than required, but does leave a remarkably fine and uniform deposit of minute crystals of DDT on all surfaces of the plants fogged. Application is rapid.

Following the first tests, the Todd engineers built a new machine, producing a particle of greater size that gives a remarkably uniform deposit on all surfaces, with better insect control.

"This is, practically, aerosol production on a field scale," they added, "and we believe it is destined to rank high as a method of application of insecticides in pest control work. Its adaptability to other than oil-soluble insecticides is yet to be determined."

Distribution of DDT in the form of smoke is also under study and showing promise.

Dosage. Many of the early uses of DDT involved dosages that now seem far too high. DDT is an extremely powerful insecticide. Considering all the evidence, one might reasonably expect that dusts of no more than 5 per cent and spray concentrations containing no more than 1 or 2 per cent, sometimes as low as 0.1 per cent, should accomplish everything that agriculture can look for in DDT. An exception is the DDT 10 per cent louse powder, a proportion that was thoroughly tested before it was adopted by the Army. In general, higher percentages of powder are required than is the case with sprays. A second exception is the 5 per cent solution for residual effect, which, since it is not applied to living tissue, can be used to obtain the full prolonged efficacy, which is a principal virtue of DDT.

As far as the use of an insecticide inside buildings goes, an important element of the situation is the difference between space sprays and residual sprays. A space spray is a form of an insecticide intended to be dispersed in extremely fine droplets or as an aerosol, so that the mist fills all the cubic space enclosed within the room. Such a dispersal eventually hits every insect in the room and, if the droplet is large enough in each case, kills it. But that ends its usefulness, and it is thus adapted to such quick-killing insecticides as pyrethrum.

DDT does not work that way. It kills slowly. But, instead of evaporating, it remains active for a long period of time. It is therefore better adapted to being sprayed on walls, ceilings, or other objects, remaining in place as a residual spray and eventually killing every insect that walks on it. Insects light eventually and die. DDT, so used, does not have to be sprayed into the air. In fact it should not be but should

be sprayed onto the walls or furniture so that the solvent evaporates, leaving the DDT adhering to the surface.

Any of the spray forms of DDT—solutions, emulsions, or water suspensions—may be used for residual effect.

A government directive holds that a 5 per cent formulation is necessary to get the proper residual effect, which is a ruling that has been consistently misunderstood. Most of those who have heard it believe that anything under 5 per cent is useless. That is not quite true. The effective dose of DDT is the dose that reaches the bug it is aimed at, and enough of a 1 or 2.5 per cent solution of DDT will kill a fly or mosquito just the same as enough of a 5 per cent solution.

The directive must be properly understood. It is only part of a measure of dosage adequacy. What the rule means is that if you wet a wall with enough of a 5 per cent solution so that it is just short of running off, you will have left on all of it a fine coating of about 200 mg. of DDT per square foot and you will use the solution at the rate of about 1 qt. to 250 sq. ft. For a long period, sometimes several months, that coating will kill practically every insect that walks on the wall.

On the other hand, if you used 1 pt. per 250 sq. ft. of a 10 per cent solution, you would put just as much DDT on the wall, but it would be in streaks. Some of the wall would not be covered. And if you used twice as much, 2 qt., of a 2.5 per cent solution, you would still be spraying just as much actual DDT, but there would be so much liquid that some of it would run off and be wasted. Actually good results have been achieved by as little as 50 mg. per square foot, but it does not last so long.

So the 5 per cent rule is a misunderstood and misrepresented part of a formula. As we pointed out, the effective dose is the one that kills the bug, and if there is only a single drop of DDT on the wall, and a bug lights on it and dies, the dose was the right one in that particular instance.

The purpose behind the formula is like the purpose of a shotgun as against a rifle. By coating the whole wall with enough to kill, you catch any bug that lights there. If you use less and do not cover the whole wall, there are DDT-free spots and some bugs will alight and live. But the 2.5 or 3 per cent solution is effective nevertheless; it just fails to get full value out of the insecticide.

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Chapter V

DDT AT WAR

WHEN war was imminent, if you remember, the public's cry was all for ships, tanks, and planes for the defense of America.

But in the secret councils of the men whose duty it was to plan and lead, the prayer was for ships, planes, tanks—and a truly good insecticide!

For, with all respect to public opinion, those men really knew what war means. They knew that America had not only to train an army but also to keep it healthy. They knew too that, among the Four Horsemen, War is always closely associated with Pestilence—and that Pestilence, despite the biblical version, is more likely to be astride a mosquito than on a horse. And they knew that if they lost the first battle to disease they stood a good chance of losing to their human enemies as well, for a sick soldier cannot fight, and typhus or yellow fever can kill fighting men in greater numbers than bullets.

And so they prayed for a good insecticide as fervently as they did for weapons.

DDT proved to be the answer, a weapon as potent against

disease-carrying insects as the B29's, the P80's, and the atomic bomb were against Germany and Japan.

WAR AND DISEASE. Disease has always gone hand in hand with war. The general disturbance of society, the failure of sanitation, the congregation of large numbers of men, the crowding of cities, and reduced nutritional levels all contribute to the establishment of epidemics. Many wars in fact have been decided according to which side had most men left after malaria, yellow fever, typhus, influenza, or some other great scourge had taken its victims. In the American Revolution both colonists and British troops were constantly harassed by scurvy, cerebrospinal fever, yellow fever, typhus, and malaria. In the Civil War, deaths from dysentery and wound infections and malaria decimated the armies during all the long four years. In the Spanish-American War, yellow fever and malaria did more damage to our troops in Cuba and the Caribbean than did the Spaniards. The First World War had its great influenza and typhus epidemics. In fact it was only in the Second World War that the total of deaths from disease was, for the first time in the history of our major wars, lower than the total deaths from wounds.

And so when war again was imminent in the world, back in 1938 and 1939, the Army's medical department began to plan and, along with the numerous vaccines and sanitary procedures and regulations, laid out an elaborate scheme for developing insecticides for the great Army that even then could be seen on the march. Extensive researches were undertaken to determine where war might find American troops fighting and what protection they would need. The answers were complex, but the principal problems, as far as insects were concerned, were mosquitoes and malaria, dengue, and yellow

fever; lice and typhus; flies and dysentery. For mosquitoes the plan was protective clothing, screens and nets, pyrethrum sprays, and fuel oil and Paris green for swamps and other breeding places. For lice the answer was a carefully developed new louse powder based on pyrethrum and rotenone. For flies the usual sanitation practices would serve.

But this plan was rudely nullified. The Japs captured the sources of rotenone in the East Indies. Labor trouble and bad weather spoiled the pyrethrum crop in Kenya, Africa. On Bataan thousands of Americans went into captivity and death, 85 per cent of them weakened by malaria. The Marines went into Guadalcanal and fought till they dropped, almost as many from malaria as from Jap gunfire. And MacArthur started back up through New Guinea from Port Moresby with his men falling out all along the bloody jungle trails because of malaria. The British, fighting on a shoestring to hold Rommel in North Africa and keep the Suez Canal, were just as badly off. And we had insufficient pyrethrum. The stage was set for Pestilence.

But it never came to pass, because in the meanwhile we got DDT and performed one of the war's great, if unsung, feats—its identification, the determination of its value against malign insects, and its manufacture in large quantities, all within the space of a few months.

Our men landed in North Africa and in all their months there contracted almost no typhus, for each of them, in addition to protective vaccine, had all his clothing saturated with DDT louse powder, 10 per cent. It was the first louse-free army in history, as those who had fought in the cootie-ridden trenches of France in 1917-1918 could testify. Malaria discipline, based on atabrine, was eventually reinforced by DDT

treatment of mosquitoes. The dysentery that plagued the British earlier was relatively infrequent among our troops. DDT, along with other triumphs of modern chemistry and modern sanitation, helped in those victories.

The Arabs soon found out about it. One of the favorite stories of the men who went through that first Mediterranean campaign concerns the black market in DDT. The Arabs paid as high as $35 an ounce for it. They thought it was a narcotic because it killed the fleas and lice that are their normal intimates and permitted them to sleep without rousing.

Then came Sicily and Italy and the story was repeated. Typhus reared its head in the civilian population of Naples, shortly after the city's occupation by American troops, and it took the greatest mass delousing program in history, based on DDT, to avert it—also a first in the history of war. A makeshift plumbing device was invented and every civilian that could be reached was backed up to it, its pipes pushed up his sleeves and trouser legs and down under his collar, and DDT powder blown into his clothing.

Neapolitan brides finally got so they laughed when DDT replaced rice at weddings. Every crowd was an opportunity to treat more people, and soldiers of the delousing squads would visit the churches, round up every one present for the ceremony, and give them a blast of DDT. But the typhus epidemic dwindled away to nothing.

Finally DDT reached the malaria-control units in the Pacific combat zones and proved an admirable weapon to supplement the effective atabrine discipline and other established measures there. Island after island was treated, first with the hand-operated devices, then with the truck-mounted

power sprayers that were quickly developed for the job, and finally with DDT dispersed from airplanes. Many islands formerly crawling with insect life were practically free of insects. Mosquito fighters flew ahead of the invasion parties to spray the combat areas and then landed with them—a few of them died—to carry on their special attack on insects. Between DDT and atabrine, added to engineering and spraying routines, malaria was ultimately reduced to insignificance as a threat to combat efficiency, while the Japs, though they had plenty of quinine, fell prey to the disease.

Since the fighting ended, American authorities have supplied DDT to combat relapsing fever, a tick-borne infection which had killed 10,000 persons in Egypt in early 1946, and to control typhus epidemics in Mexico, Japan, and Yugoslavia.

BEHIND THE SCENE. DDT came to America from Switzerland. A great deal has been made of the fact that it was originally synthesized by a German chemistry student, Othmar Zeidler, in Strasbourg in 1874. Actually his part in the story has no significance. Chemistry was in an almost primitive stage then, and Zeidler was investigating and reporting a series of compounds to get material for his doctoral thesis. He simply recorded his notes in six lines in a professional journal and forgot about it. There are thousands of such compounds in the university and industrial research laboratories—tours de force in pure science—and no one has any idea what they will do. Zeidler's was just another.

The story actually begins about 1938 when a Swiss chemist, Paul Müller of Basle, working from some chemical clues toward a new insecticide, again synthesized dichlorodiethyltrichloroethane. In early tests on clothes moths and flies it

seemed to work remarkably well. Then he found it killed mosquitoes, and he eventually established the prolonged action that characterizes it and discovered that it was both a contact and a stomach poison.

In 1939, just about the time the German armies were moving into Poland and Switzerland was having trouble getting outside chemical shipments, the Colorado potato beetle, which had gone to Europe with the American Army's supplies in the First World War, struck the Swiss potato crop. DDT got its first major test. It destroyed the beetle and saved the crop. Tests then showed that it was effective against a number of other insects common in Switzerland, including lice.

By 1942—the United States was then in the war—its value was well established. The Geigy Company, Swiss dye house which owned the patent on the material, offered it to the American Army, and a small shipment was sent to this country as a potential lousicide.

It was received with suspicion. Just previously the Germans had staged a fear propaganda campaign about the new "nerve poisons" developed by German chemists—part of the "war of nerves," presumably. And when the first tests of DDT brought insects down in convulsions, obviously due to nerve effects, the first thought was that maybe this was the nerve poison. Further testing shortly dispelled the idea, however, and the work went forward.

After the first samples, a shipment of 100 kg. (220 lb.) came to this country and was turned over to the U.S. Department of Agriculture for study. Dr. F. C. Bishopp and Dr. F. C. Roark of the Bureau of Entomology and Plant Quarantine arranged some tests. The results were so spectacular that,

knowing the Army was in trouble over lack of pyrethrum, they went to Maj. Gen. Norman T. Kirk, Surgeon General of the Army, and Brig. Gen. James S. Simmons, chief of the Army's Preventive Medicine Service, with the story. Col. William S. Stone, then director of the sanitation and hygiene division of the Surgeon General's Office (later succeeded by Lt. Col. A. L. Ahnfeldt), immediately organized a full-scale research program to outline its value. Their hope at that time was to find something that would conserve the dwindling supply of pyrethrum for use in louse powders. Under Dr. Walter E. Dove, chief of the division of insects affecting man and animals, Bureau of Entomology and Plant Quarantine, a special laboratory with a staff of 29 men was established at Orlando, Fla., in charge of E. F. Knipling.

It was there that the job of developing DDT was largely accomplished. The story, if it is ever released, will be of great interest. Starting from scratch, they kept on that way, so to speak. For instance, they had to build up their own colonies of lice for test material, since that was at first their major interest. Bureau men went to the jails in cities up and down the East Coast, shook down the prisoners for their insect companions, fed the lice on their own arms to fortify them for the trip, and then shipped them to Orlando. The problem of feeding several hundred thousand lice, after the staff volunteers had run out of surplus blood, was solved by hiring local people who served their country by going to the laboratory once a week and letting some thirty to forty thousand lice feed on their backs.

But by the spring of 1943 the safety and effectiveness of DDT powder as a lousicide had been well established, and on May 26, 1943, the first order fixing on a 10 per cent DDT

powder in pyrophyllite as the Army louse powder was issued. Wherever louse-borne typhus existed, every American soldier or sailor received a 2-oz. salt-shaker-type can of this powder monthly, with instructions to sprinkle it in his clothing. There was never a case of DDT poisoning, and probably no soldier or sailor had lice, if he used the powder.

A year later Colonel Ahnfeldt said in a talk before a New York audience:

> The first field studies on DDT were carried out in the fall of 1943 in North Africa by Army medical officers, in co-operation with the U.S.A. Typhus Commission and investigators from the Rockefeller Foundation. Here the most important development of the century in the field of typhus control was demonstrated. It was shown that, with as potent a lousicide as DDT, mass delousing of troops, prisoners, refugees and the civilian population could be successfully carried out by simply blowing or dusting powder under the clothing by means of a hand spray gun fitted with a rubber nozzle or powder dusters utilizing compressed air.
>
> One experiment is typical of the experience gained in such methods. In one prisoner of war camp 252 men were selected as a group. Lice were found on 77 per cent of these men. The entire group was then dusted with DDT louse powder. Re-examination of 151 of these men 16 days later failed to reveal a single louse.

With that type of experience at hand, the Army was ready to fight the typhus epidemic in Naples in December, 1943, and January, 1944, an epidemic carried back to Italy, after Italy's surrender, by Italian troops returning from Yugoslavia, where the disease is endemic. The mass-dusting stations were set up all over Naples, each manned by 6 to 20 persons, some of them dusting as many as 5,000 persons a day and altogether

handling about 50,000 a day at the height of the campaign. By mid-March more than 2,250,000 persons had been deloused. The epidemic was stopped, and no American soldier in Italy got typhus.

Meanwhile the research was still going on rapidly. The original powder would wash out of Army garments, so an emulsion was developed that would stay effective on the garment through eight washings, even with G.I. soap. DDT was added to the aerosol bomb, previously a pyrethrum device. The mosquito possibilities were explored, and the residual-spray technic worked out, followed by various sprayers and the airplane methods. Slow planes were used at first, but eventually a pump and nozzles were perfected that would deliver the solution or emulsion fast enough to enable it to be distributed from a combat plane.

Finally General Kirk set up the Army Committee for Insect and Rodent Control, with Colonel Ahnfeldt as executive chairman, to handle for the Army not only the DDT research but also the work on rat poisons and insect repellents from all angles, in cooperation with the Office of Scientific Research and Development, the National Research Council, the Navy, the U.S. Department of Agriculture, the U.S. Department of the Interior, the U.S. Public Health Service, and other agencies.

The Army and Navy also used much DDT around military establishments at home and, as the supply became greater, undertook the task of cleaning up flies and mosquitoes around war plants where they were especially bad. These uses, plus the continuing work of the U.S. Department of Agriculture, gradually drove home the realization that DDT was an outstanding insecticide, something far better than had ever been

available previously. Extensive research programs in agriculture, forestry, fruit crops, and other specialties began to be undertaken by the department.

From the early stages of the research work, various rumors about the new miracle insecticide had been in circulation among the general public. Publication of the Naples story gave them impetus, and the process was speeded by soldiers' letters back home. It was from such sources that DDT had developed its tremendous publicity build-up in the public mind by the time the government released it for civilian use in September, 1945. Many government experts, particularly those who had been working with it, would have preferred to withhold it for a much longer period, but the demand was so great that they had to yield. Actually when large quantities became available instead of the relatively small amounts doled out previously for research work, many state and private laboratories began to investigate it, so that the task of evaluating it has been enormously hastened. But the job of scientific research and practical application combined with what the Army, the U.S. Department of Agriculture, and the chemical manufacturers did on DDT during the war stands on a par with such feats as radar and the atomic bomb. The record of disease control established by the American services in the war in the face of tremendous difficulties is testimony to it—backed up by the return to their homes of thousands of young men who would otherwise have died somewhere far away of infectious disease. DDT played an important part in the achievement.

Chapter VI

MAN'S HEALTH AND COMFORT

WHEN an insect bites a human being, it may sometimes transmit disease, but it always creates discomfort. Although history shows that the insect-borne disease is the more important in the long run, the more immediate annoyance is likely to be the impressive fact to the victim. Hence most of us, learning for the first time of DDT as a new miracle insect killer, think rather of summer days free of flies and summer evenings without mosquitoes, of roachless houses and flealess dogs, than of a world without malaria or typhus.

DDT, however, holds out promise of satisfying both of mankind's yearnings: control of insect-borne disease and freedom from insect pests. We have already seen what it did for fighting men against malaria and typhus. It can do as much and a great deal more for civilians.

Health

The importance of insect-borne disease cannot be overestimated, and, if DDT does nothing else but give man victory

over such infections, all the time and money and energy spent on it will be well worth while. Let us look at some of the facts behind that statement.

MALARIA. Deaths from this mosquito-borne disease have been estimated at 3,000,000 a year throughout the world. It is blamed for the collapse of the classical civilization of Greece and Rome, and it has been with our civilization ever since, endemic, slow, deadly. Shakespeare's Brutus warned Caesar not to "dare the vile contagion of the night" and the early colonists of New England had their "ague" or "chills and fever" regularly each summer. With yellow fever, it nearly stopped the Panama Canal plan.

In the Northern United States, however, it has practically disappeared as a menace, and few of us thought much about it until it struck our men in the Pacific and North Africa and Italy. In southern states, on the other hand, it is an ever-present menace still, despite the discovery of cinchona bark (source of quinine) in Peru in the late sixteenth or early seventeenth century. Recently the U.S. Public Health Service has opened an intensive campaign, based on DDT, from headquarters in Atlanta, Ga., to bring it under control. Taking advantage of the night-biting *Anopheles'* habit of resting for long periods on walls and ceilings, its men are spraying thousands of homes with DDT solutions and suspensions to eliminate the pest.

Malaria costs the United States at least $500,000,000 a year, according to an estimate by Dr. Louis L. Williams, Jr., of the U.S. Public Health Service, with some 4,000,000 cases and 4,000 deaths ascribed to it as a yearly average. India's victims, to show the magnitude of the problem, are estimated at 100,000,000 and its annual deaths at 1,000,000. The eco-

nomic loss is equally staggering. Large areas of fertile land are uninhabitable because of malaria. Time lost from work in southern states is estimated at one-third and higher where the falciparum type of the disease prevails.

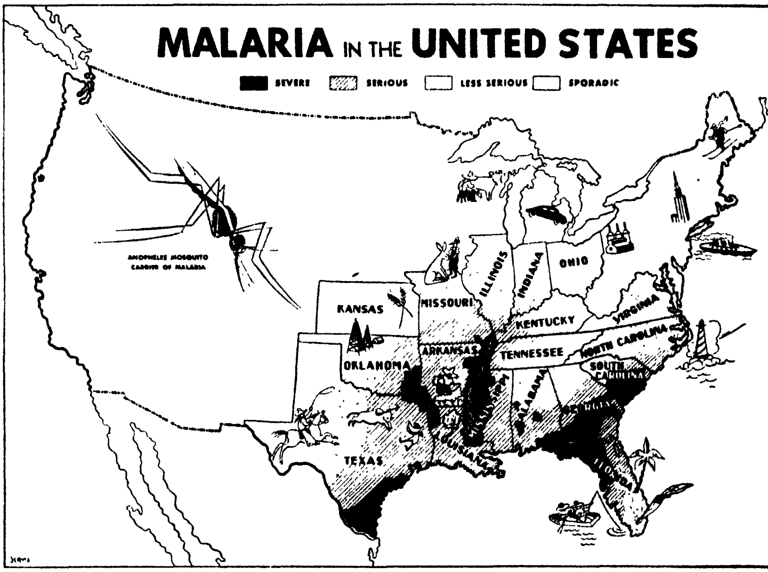

FIG. 1.—The prevalence of malaria in the United States. A large important field of use for DDT lies in controlling the *Anopheles*, which is the carrier of malaria. Formerly, malaria was a menace to life and health throughout the northern United States as well, but mosquito control measures have largely eliminated it there, as the map shows.

YELLOW FEVER. This disease, transmitted by the bite of the *Aedes aegypti* mosquito, has spread all over the world in its day, but it has always been a disease of the ports, as far as the United States is concerned. A ship from West Africa would bring the mosquitoes, breeding in her water tanks, and unload them with her cargo, and the epidemic would break out. Yellow fever, a virus infection, kills some 60 per cent

of its victims in 4 or 5 days. In 1793, 4,000 of Philadelphia's 40,000 died of it, and there have been many minor epidemics. There is no treatment for it, though recently a vaccine has been developed. There has been little yellow fever in this country in recent years, though it was a serious problem among our troops in the Spanish-American War and later in the building of the Panama Canal.

SLEEPING SICKNESS. It is only recently that the third major group of mosquitoes, the *Culex*, has been indicted as the vector of infectious encephalitis,[1] or sleeping sickness, a virus disease which breaks out in epidemics affecting both man and animals. It is severe and often fatal, and it frequently leaves aftermaths in the form of mental or nervous symptoms. It is endemic in the United States.

FILARIASIS. *Culex* also transmits filariasis, an infection of the blood and lymph streams with a microscopic nematode worm. In the United States it has been found only in the neighborhood of Charleston, S.C., but in the Pacific the strange distortions of the human body caused by it are a common sight. Several species of mosquito transmit it there. Masses of worms clog lymph channels and cause legs or scrotum to swell into huge caricatures, a condition known as elephantiasis. There is no satisfactory treatment, though some forms of antimony and arsenic have given promise of value.

DENGUE. Dengue is a fifth disease transmitted by mosquitoes, again the *Aedes aegypti*. To serve as vector the mosquito must bite a victim within the first 48 hr. of his fever, then wait 12 days before it can pass the virus to someone else. It is rarely fatal, but its common name of "breakbone fever" suggests the pain associated with it. Convalescence

is protracted, due to mental and nervous weakness. It is endemic in the tropics in the Western Hemisphere.

PLAGUE. Bubonic plague, the Black Death, has swept across the world twice, in the sixth and the fourteenth centuries, on the second occasion destroying one-fourth the population of Europe. The causative organism, *Pasteurella pestis*, uses the rat as a reservoir and reaches man by means of the rat flea (*Xenopsylla cheopis*). It kills some 75 per cent of its victims in 3 or 4 days, whether it takes the bubonic or the pneumonic form, while a third type, septicemic plague, kills so quickly that the victim has no time to develop symptoms. The current appearance of plague began in Hong Kong in 1894, spread around the Pacific to San Francisco, and now by way of wild rodents has gotten as far east as western Kansas, where the disease has been found in rodents.

THE TYPHUS FAMILY. The rat flea shares with the louse (*Pediculus corporis*) the task of transmitting typhus fever, one of the top few among the great curses of mankind. The flea passes along the murine form, which does not often become epidemic and has a mortality rate of about 1 per cent in the United States. The major job, that of transmitting the epidemic or European type, is left to the louse (cootie or crab). It is therefore a disease of filth, and mankind becomes filthy when war and disaster prevent him from keeping himself clean. Epidemic typhus is endemic in the Balkans, Russia, China, Spain, Chile, and Colombia.

One of DDT's great wartime achievements was the elimination of a budding epidemic of typhus shortly after our troops reached Naples, as we have seen. The Army louse powder, which had kept our troops free of the cooties that plagued their fathers in the First World War, stopped the outbreak

successfully, the first time such a feat had ever been achieved (see preceding chapter).

Typhus, caused by *Rickettsia prowazeki*, is one of a group known as rickettsial diseases. The epidemic type is due to *Rickettsia prowazeki prowazeki*, the murine to *Rickettsia prowazeki mooseri*. The name *Rickettsia* pays tribute to a University of Chicago investigator, Howard Taylor Ricketts, who died of typhus in Mexico in 1910, after having been first to identify the group of organisms. They are not quite like ordinary bacteria, but neither are they filtrable, and they require special technics to grow and stain them and thus make possible the preparation of vaccines and antiserums. All American troops are protected by a typhus vaccine.

The third most important member of the rickettsia group is Rocky Mountain spotted fever, due to *Rickettsia rickettsii*, the agent Ricketts first saw. This is a tick-borne disease, carried from reservoirs in wild rodents by the dog tick (*Dermacentor variabilis*) in the Eastern and Southern United States, by the wood tick (*Dermacentor andersoni*) in the Northwest, and by the lone-star tick (*Amblyomma americanum*) in the Southwest.

A fourth rickettsial infection, not current in the United States so far, but one of the new diseases which greeted American troops in India, Burma, New Guinea, Australia, and other Pacific areas, is "scrub typhus" or Tsutsugamushi disease, believed due to *Rickettsia orientalis*. There were many cases among our men. It is transmitted by mites, principally *Trombicula akamushi*, from infected wild rodents.

Several other rickettsial infections have been recorded, but only one, Q fever, due to *Rickettsia burneti*, in the United States.

FLIES. Flies may carry many diseases, too, more familiar than some of those just mentioned. In most cases, however, they are not the only means of transmission to man. In the list are anthrax, common to man and cattle, cholera, the dysenteries, paratyphoid, typhoid fever, yaws, and tularemia. What other less specific bacteria, such as the streptococci and staphylococci, they transport from filth to human food, for instance, it is difficult to say.

There are numerous other insect-borne diseases, *e.g.*, the relapsing fever carried by ticks and lice, the sand-fly fever carried by a small bloodsucking midge to many of our men in the Far East, the African trypanosomiasis or sleeping sickness carried by the tsetse fly, which the airplane has made a threat to the Western Hemisphere; the American form, known as Chagas disease, common in Central and South America and recently found in wild rodents and the cone-nosed assassin bugs (*Reduviidae*) that carry the parasite in California, Arizona, and Texas.[3]

Comfort

Aside from the infections spread by mosquitoes, flies, ticks, and fleas, these and other insects (or arachnids, if you insist) plague mankind by biting him, destroying his comfort, damaging his property, smelling up his home, or just by being around him. The list here is much longer—flies, mosquitoes, fleas, ticks, mites or chiggers, gnats, bedbugs, lice, cockroaches, spiders, silverfish, ants, termites, moths, and carpet beetles.

The flies are dirty; they buzz, crawl, tickle, and sometimes bite viciously. The mosquitoes bite man and his dog or cat; so do fleas, ticks, mites, lice, bedbugs, gnats, and often ants.

And when they do they make him itch. Bedbugs also stink; so do cockroaches. What is worse, they have a distinctive and recognizable odor. The ants, termites, moths, silverfish, and carpet beetles eat the wood of his home or his woolen clothing or rugs or blankets. They frighten his wife and children and cast reflections on the quality of his or her housekeeping. The silverfish, nasty little "primitively apterous" things ½ in. long, with grayish armor plate and three tails and two feelers, even eat rayon and bookbindings.

The U.S. Department of Agriculture a few years ago estimated that clothes moths alone cost American citizens some $22,000,000 annually. Termite damage runs up to $40,000,000, including control measures, housefly expense to $66,000,000, and mosquito expense to $145,000,000. The figures, of course, include such items as time lost due to malaria. On the other hand, along the New Jersey coast it was estimated that mosquito-control measures had been principally responsible for raising property values over a 20-year period by $100,000,000. Substantial sums, all of them, for such a tiny insect! But there is no need to belabor the point; no one lives in the United States in this year of 1946 who needs to be told of these pests.

Controlling Insects Affecting Health and Comfort

But maybe the next generation will not be so familiar with them—if DDT carries out its promise. For DDT—properly used—can control them, with the exception of chiggers and some mites and ticks.

Flies and mosquitoes yield readily to the effect of a 5 per cent residual coating on walls, ceilings, and screens. The

liquid can be applied with a spray, with a paint brush like kalsomine, or with a felt-roller applicator such as is used to paint screens. It is from such use that the householder will derive fullest benefit from DDT. A pyrethrum spray, for instance, will knock down and kill almost instantly most of the flies and mosquitoes in a room if the air is filled with the droplets. But when the mist settles, its work is practically over. More insects buzz in and settle down to work in safety.

But not with DDT. Both insects have a habit of finding a nice comfortable spot on walls or ceilings—resting places, the entomologists call them. When the wall is covered with DDT, however, there are no comfortable resting places. To light for a few minutes means death. The liquid in which the DDT is dissolved evaporates and there is an invisible, stainless coating of the chemical on every square inch of resting place—if the job has been properly done—and the insects' habit of resting is their undoing. Shortly they begin to fly around, even more aimlessly than they usually do. They light again, even fly out of the room or out of the house, seeking to escape the poison. They lose control of their legs, but not their wings, and so fly some more. Then the wings fail, and they end up on the floor in convulsions. The spasms gradually ease down to the level of mild, incoordinated kicking as the insects lie on their backs. Then they die.

The solution (or suspension or emulsion) should be sprayed wherever flies rest—not only on walls or ceilings but on the tops of doors, on electric-light cords and window frames, and on screens and the undersides of tables and chairs. Don't get it on glass; it is insoluble in water and takes kerosene or

some other oil to remove it. Don't get it on varnished surfaces; the solvent may spoil the finish, though it does not hurt paint. It is probably better and less wasteful to paint

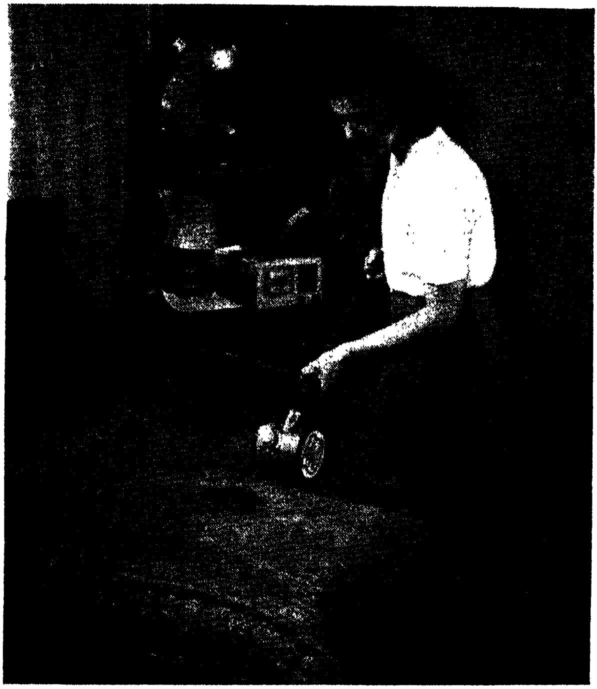

FIG. 2.—DDT in the home. DDT is the most valuable weapon yet found against bedbugs. Bedding, mattresses, springs, bedstead, walls, baseboard, and other objects near by should be thoroughly sprayed with a 5 per cent solution. *(Courtesy of U.S. Department of Agriculture.)*

DDT on screens. It should be sprayed generously on and around garbage cans. To get all the mosquito resting places it is necessary to cover dark corners, walls behind pictures and furniture, the undersides and backs of bookcases, chairs, tables, and similar objects, as well as closets and porches.

It is against flies and mosquitoes that DDT in aerosol form is most often used—the DDT bomb. Actually the quick kill obtained from the aerosol emitted by the bomb

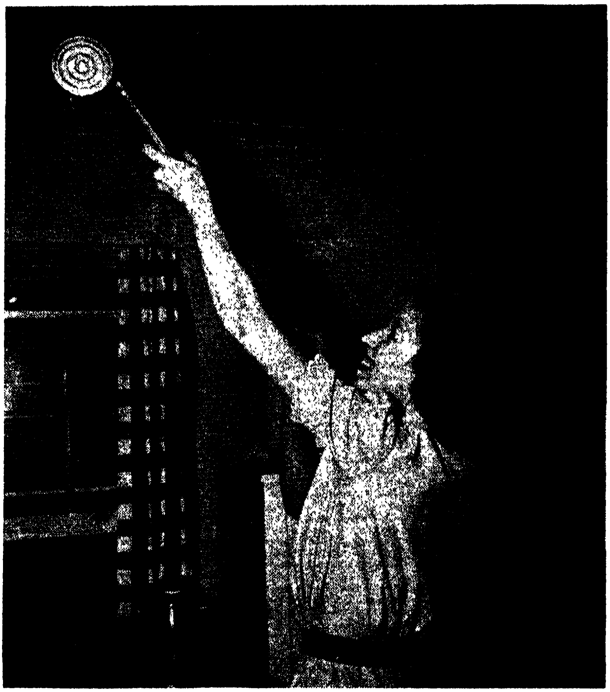

FIG. 3.—DDT in the home. A 5 per cent solution of DDT sprayed on walls, ceilings, and other resting places of flies and mosquitoes will eliminate them from buildings. One application, at the rate of a gallon per 1,000 sq. ft., may last for months if not subject to weathering, especially direct sunlight. (*Courtesy of U.S. Department of Agriculture.*)

is obtained by a mixture of pyrethrum or some other insecticide. DDT does not kill that quickly. Theoretically the value of the DDT is to reinforce the killing action of the pyrethrum by adding a little more poison to finish off an insect

that has not received a killing dose of pyrethrum. Experts consider this a rather wasteful use of DDT, for it does not take advantage of the prolonged action of DDT; little of it

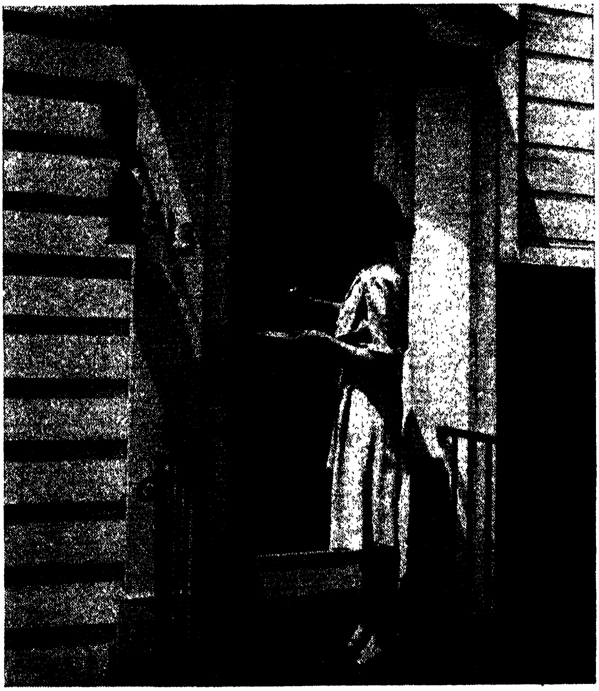

FIG. 4.—DDT in the home. Use of a 5 per cent solution or water suspension of DDT on screens, doors, window frames and near-by areas helps to control flies, mosquitoes, and various other insects, as they seek entrance to buildings. To avoid waste, the application should be painted rather than sprayed. Because it is subject to weathering and direct sunlight, the application should be repeated every ten days to two weeks. (*Courtesy of U.S. Department of Agriculture.*)

is deposited as a residue. But it is spectacular and satisfying to the user.

The final value of DDT against flies and mosquitoes is in

control of their larvae. Flies breed in such places as manure piles, the larvae often being found on the ground near by. It is easy to lay a residual coating of the 5 per cent solution

FIG. 5.—DDT in the home. DDT is effective in powder as well as liquid form. The picture shows the use of a blower to place the 10 per cent powder behind a baseboard as protection against cockroaches, brown dog ticks, or bedbugs. In either spray or powder form, it should be directed forcefully into all sorts of cracks, corners, or crannies where insects might hide. (*Courtesy of U.S. Department of Agriculture.*)

around such areas so that the insects never grow up to fly into the house.

Mosquitoes breed in water, and the larvae are the wigglers seen in most stagnant pools in summer. The DDT oil solu-

tion floating on top of the water kills them as fast as they hatch. This is one of the valuable methods developed by the Army, which achieves it in combat and camp areas by airplane distribution. A relatively light dosage in either dust, solution, or emulsion form is used by the Army. As little as 1 lb. of DDT to 250 acres of water surface kills off the larvae of the malaria mosquito (*Anopheles quadrimaculatus* Say) and probably most others.

For the domestic user, however, any application of whatever DDT formula he has at hand in reasonably generous quantities to fishponds, swampy areas, stagnant water, rain barrels, and other breeding places, not forgetting roof drains, will serve to cut down the number of mosquitoes entering his home or barns. The residual effect here is not so great as when DDT is applied to walls. Wind sweeps it into a corner on large expanses of water, and some sinks to the bottom.

Probably the major part of the use of DDT against mosquito larvae will be on a community basis, with the county or municipality or mosquito-abatement district spraying swamps and other large-scale breeding places. But the householder can help by cleaning up the small spots around his home.

Other uses of DDT against flies [9] follow:

Application of a 1 per cent DDT dust at 15 lb. per acre to shrubs, bushes, tees, and greens of a golf course in the Upper Peninsula of Michigan protected golfers for a week from the black fly (*Simulium venustum* Say). In Wisconsin a 2 per cent solution on the walls of a sewage-filtration plant killed filter flies (*Psychodidae*) as they hatched and rested, while a 5 per cent kerosene solution on sludge beds killed the maggots. In Florida the 5 per cent solution, applied to

screens, killed sand flies (*Culicoides* spp.). It was ineffective against larvae of the soldier fly (*Hermetia illucens* L.) in latrine pits, but when sprayed on screens killed the adults.

For fleas the powdered form is usually recommended—10 per cent DDT in pyrophyllite. Fleas, it should be recalled, enter a home largely by way of its pets—dogs or cats in most instances. They take a blood meal and then drop off into a rug or upholstered chair or a warm cranny somewhere to digest it. When hunger moves them they hook onto the next warm-blooded creature that comes near, you or the baby or the dog, for instance. Again the entomologists have learned to take advantage of the insect's habits. Spread the powder around the pet's sleeping places, into cracks and crevices where the flea larvae might be hiding. It is also safe to dust about a tablespoonful of the powder into a dog's coat. He need not be completely covered; a ring around his neck or abdomen or a line along his spine is usually enough, for the flea moves around. Cats lick themselves, however, and may swallow enough of the chemical to affect them. We have seen that they are highly susceptible to it. For fleas on cats a thorough dusting of the sleeping places will be sufficient, together with the general applications throughout the house. Oil solutions of course should never be applied to animals. They can absorb DDT by way of the skin in that form as efficiently as can human beings.

The story of DDT and lice is too familiar to warrant much detail. DDT spells death to them anywhere. Every soldier and sailor used the 10 per cent DDT dust as a louse powder, and the American forces were free of cooties for the first time in any war. It is entirely safe; it is not absorbed. It should be dusted through the clothing, government bulletins recom-

mend, with special attention to the seams, to control body lice. Head lice die of a teaspoonful of the powder carefully spread through the hair. Similar technics on body, pubic, and armpit hair will destroy crab lice. It is important to remember that DDT is not an ovicide—it does not kill eggs. Therefore the treatment should be repeated in 8 to 10 days, to catch any that might have hatched. Clothing treated with DDT will remain toxic to lice even after being washed in warm soapy water. If it is not washed the treatment is good for 3 weeks.

The U.S. Department of Agriculture calls DDT "the perfect answer" to the bedbug problem, whether applied as the 5 per cent spray or the 10 per cent powder. It lasts for 6 months or more. About 3 oz. of spray or 1½ oz. of powder is required for each bed and must be worked well into every joint and cranny in the bedframe and applied lightly to mattresses and pillows. Bedbugs must have a blood meal, and they die when they approach the sleeper protected by DDT. In heavy infestations the U.S. Public Health Service advises application of DDT to walls, baseboard cracks, behind loose wallpaper, and to any other hiding places. Otherwise treatment of the bed itself is enough. A complete kill may take 48 hr.

Cockroaches are a more difficult problem. These canny insects, for which sodium fluoride was the only really effective poison previously, have a knack of defeating most attempts to control them. The small German cockroach (*Blattella germanica* L.) is even more difficult to kill than the large American roach (*Perplaneta americana* L.). In fact the earlier reports on DDT omitted both roaches from the list of insects it would kill. Later work showed this to be unwarranted,

however, and now it is well known that DDT is effective against both. In an Army-base messhall chosen for testing because of heavy infestation, both sprays and dusts were used successfully. In one building 2,000 dead cockroaches were on the floor within 30 min. of spraying, and 24 hr. later there were so many it was deemed advisable not to use the place until they had been cleared. The sprays worked more quickly, but the dusts were better in the long run, it was reported. These tests involved only German roaches.

In another test, roaches were allowed to run once across a narrow band of 5 per cent DDT dust, and one-third of the German roaches died in 96 hr. while 100 per cent of the American roaches were dead in 48 to 72 hr. Sodium fluoride was not so efficient.[4]

The U.S. Public Health Service recommends a combination of spray for immediate control plus dust for places not reachable by the spray. In the South, where roaches breed outdoors, continuous reinfestation is possible, and it is necessary to repeat the treatment more often, but in other areas one treatment is often good for as long as a month. The application should be thorough, covering the undersides of tables and refrigerators as well as all cracks and crannies, such as the openings around water pipes, where the insects move.

A similar treatment is good against many species of ants, covering with the spray the baseboards, window sills, and sink areas, working the chemical behind them and including also table and chair legs, pantry shelves, and crevices leading outside. Not all species of ants have been found to respond to DDT, however.

There was doubt for a while whether DDT was good against clothes moths and carpet beetles, but more recent work by

the U.S. Public Health Service has shown it is. Sprays should be used on all clothing surfaces, the insides of trunks and closets and other storage spaces, on and under rugs and furniture, on baseboards, and in floor cracks where dust and lint might gather.

Silverfish have been studied in many places, and reports all show that DDT can control them, by means similar to those taken against cockroaches and ants.

For gnats, sand flies (no-see-ums, punkies), and similar tiny biting insects that pass through screens and are thus extremely difficult to control, DDT is fatal, if it can be brought into contact with them. A heavy application of DDT in liquid form painted on screens so that they make contact with it on the way in is believed to be the best attack. The residual spray on walls near lights is also valuable.

As to termites, the story is incomplete. Laboratory tests show that DDT will kill them, but the problem, in view of their peculiar habits, is to bring them into contact with the poison. A 3 per cent dust mixed with sand repelled them, but in field tests they mostly avoided the poison. There are so many species and they vary so widely in their habits and tastes that it will probably be a long time before DDT's full value is achieved against them.

Ticks are another unusual problem. Apparently a tick is susceptible only at times to the attack of DDT. Many of the men who have handled the problem believe that a tick engorged with the blood of a warm-blooded animal can resist the poison successfully. Others believe that the tick's trick of shedding its skin protects it; the old skin is not penetrated by the poison. They say, too, that a newly emerged tick may crawl over a DDT-impregnated castoff skin and die.

There are about 30 species of ticks of importance in the United States, experts estimate; about half of them bite man.

The brown dog tick (*Rhipicephalus sanguineus* Latr.) seldom attacks anything but a dog but crawls on walls and looks something like a bedbug and may transmit animal disease. Often a dog, especially in Southern states, will be found with an enormous infestation. A 10 per cent DDT powder is recommended for treating the animal. Since the ticks do not move after they once attach themselves, the poison must be distributed all over the animal's body, rubbed into the fur with a gloved hand or a brush. The powder scattered around the house, under rugs and in crevices, will also help in their control. These ticks are not easily killed, but they are susceptible at certain times, as when newly hatched or recently shed, and the powder must be left in place for 2 weeks.

The American dog tick (*Dermacentor variabilis*), which can transmit Rocky Mountain spotted fever, can be controlled with a fair degree of effectiveness in its hiding places in roadside foliage. DDT, experts say, seems to have little effect on the tick on the dog. DDT has been reported effective against the lone-star tick (*Amblyomma americanum* L.) on a short-haired dog, when applied as 5 per cent emulsion, but a 20 per cent spray in benzyl benzoate was ineffective on a collie.

Mites and chiggers, like the ticks, are eight-legged creatures belonging to the arachnid class and are not properly called insects. Against both mites and chiggers, DDT is not regarded now as being particularly effective in comparison with sulfur and some other chemicals, though it seems to kill some of them. More study is required to improve technics of application.

The success of airplane sprays and of intensive hand spraying on a community-wide basis, such as the U.S. Public Health Service has been doing in 11 Southern states as part of its malaria-control work in war areas, opens up a new possibility in the use of DDT—regular city-wide insect-extermination programs. Many experts in the use of DDT do not believe at the moment that airplane spraying is effective use of DDT. Because it does not involve utilization of its long-lasting residual effect, they consider it wasteful. However, for cities where pollination is not important—the closely packed apartment-house areas—an airplane spraying every 2 weeks or so might be valuable. It is of course a successful method of attacking mosquito larvae.

The American Municipal Association recently reported a number of instances of community use of DDT and quoted city officials as calling the results "marvelous" but warned that opinions are not unanimous. At this time it is rather something to think about. During the summer of 1945, U.S. Public Health Service men and Army Air Force pilots and planes were loaned to The National Foundation for Infantile Paralysis to spray four cities—Rockford, Ill., Savannah, Ga., Paterson, N.J., and New Haven, Conn.—to cut down the fly population, strictly as an experiment to determine whether it would reduce outbreaks of infantile paralysis. No reports are yet available, but the general impression was that it was futile. Other communities, stimulated by the general interest in DDT and manifesting man's weakness for snatching at everything offered as a panacea, went into expensive hand-spraying operations for the same purpose. They killed flies and mosquitoes—a worthy feat, of course—but probably did not influence the infantile paralysis.

A number of other cities—Hartford, Conn., Los Angeles, Calif., Richmond, Va., Cleveland, Ohio, Savanna, Ill., for instance—have been using DDT in various large-scale insect-control programs, either in public buildings or for malaria control in business establishments. A Milwaukee public-housing project has been experimenting with DDT paint on walls, and in Florida a county has been spraying dairy barns.

When we learn more about the use of DDT—how to get full value from it—many of these experimental ideas will reach a development that will set new standards of insect-free comfort for American cities.

LIVESTOCK AND POULTRY INSECTS. A number of insects that affect livestock and poultry have been shown to yield to DDT. However, it has not so far been used successfully against either the heel fly, source of ox warbles and damaged hides, or the screwworm, a fly larva usually infesting wounds, sometimes fatally.

Ticks. Results of dipping for ticks on livestock are erratic, but a substantial number of reports from varied sources indicate value. A heavy enough concentration to remain long enough to cover the life cycle of the tick is apparently required. A South American report was enthusiastic about a mixture of DDT and rotenone as a liquid for spraying. Its effectiveness is not due entirely to the rotenone, for the report indicated that DDT's value lasted up to 80 days.

In the case of the Gulf Coast tick, a new type of application has been devised—a DDT solution in a nondrying adhesive material. This tick prefers the ears of animals, and coating the interior of the external ear with the new material keeps the insect in position long enough to be killed by the poison. Ticks are found attached but dead. The importance of this

tick (*Amblyomma americanum* Koch) lies in the fact that, from Aug. 1 to late October, 85 per cent of all screwworm infestation in southern coastal areas begins in their bites. The treatment, devised by W. G. Bruce and A. L. Smith and tested on some 1,500 cattle, cut the infestation [9] from nearly five ticks per ear to an average well under 1 per cent.

A 0.9 per cent emulsion of DDT in pine oil applied with a sponge killed [9] all existing winter horse ticks (*Dermacentor nigrolineatus* Pack.) on 35 horses and kept them free for 60 days. A 5 per cent solution in kerosene, applied thoroughly in poultry houses, kept them clear [9] of fowl ticks (*Argas miniatus* Koch) for 3 months.

The sheep tick or ked (*Melophagus ovinus* L.), which is really a wingless fly, attacks sheep and Angora goats, causing them to scratch and damage fleece and hide. A pine-oil emulsion containing 0.2 per cent DDT, tested on 3,400 sheep and 1,560 goats on a Texas ranch, killed all the ticks [11] and kept the animals free for at least 75 days.

Mites. The scab mites (*Psoroptes cuniculi*), which often infest the ears of laboratory rabbits, can be controlled by spraying small quantities of a 5 per cent solution [2] on the inner surface of the ear. Sometimes several applications at 3-day intervals are needed. One application is useful in prophylaxis.

Lice. A North Dakota report [5] told of preliminary tests with a 10 per cent DDT dust in pyrophyllite which "gave fairly satisfactory control" of the short-nosed cattle louse (*Haemotopinus eurysternus*) and the cattle chewing louse (*Bovicola bovis*).

> In these tests, three yearling steers heavily infested with the chewing lice and three two-year-old heifers moderately infested with the short-nosed cattle lice were used. Examination

made 24 hours after the application of the dusting mixture showed all the chewing lice and upwards of 90 per cent of the short-nosed lice destroyed. Three weeks following the application, light infestations of recently hatched lice of both species were observed on the treated animals. Five weeks after the application the infestation of both species of lice disappeared completely from these animals.

Sprays and dips in a 0.2 per cent DDT emulsion (triton-xylene mixture) are also satisfactory treatment for lice, though sometimes the xylene tends to irritate the animals' eyes for a short period. An emulsion of 20 per cent DDT in pine oil, a water-dispersible mixture diluted down to the proper percentage, is also effective. About ½ gal. is required to spray the average animal, and the DDT deposit would amount to 4 or 5 g.

A Texas test [9] added the long-nosed bloodsucking louse (*Linognathus vituli* L.) to the list, noting that more than one treatment was needed to kill all lice. It indicated that dipping in a 0.2 per cent emulsion was more effective than spraying or dusting. On goats, red and yellow biting lice (*Trichodectes* spp.) and the blue bloodsucking louse (*Linognathus* spp.) disappeared "for more than 99 days" [9] after dipping the animals in a 0.2 per cent pine-oil emulsion. The fleece clipped from such animals killed 85 per cent of the larvae of carpet beetles (*Attagenus piceus* Oliv. and *Anthrenus vorax* Waterh.) to which they were exposed in a test for 3 months.

The same emulsion, after two treatments, eliminated all stages of the hog louse (*Haematopinus adventicus* Newm.) for a week. Treatment of a few animals cut the infestation rapidly because of the hogs' habit of bedding together.

Dusting individual hens with a 5 per cent pyrophyllite powder freed[9] them of lice in Texas, while in Kansas[8] a 3 per cent dust gave "fairly effective" control of chicken body lice.

FIG. 6.—DDT on the farm. A 5 per cent water suspension of DDT applied at the rate of a gallon per 1,000 sq. ft. (or more heavily on highly absorbent surfaces) is effective in the control of various flies that infest barns and other buildings. The use of hand- or motor-operated sprayers with a long nozzle simplifies the task. (*Courtesy of U.S. Department of Agriculture.*)

Flies in Barns. A heavy DDT spray—5 per cent solution or suspension—sprayed on walls and partitions clears barns and other buildings for the protection of dairy and other cattle, as successfully as it clears human habitations. This residual spray, used at the standard 1 gal. per 1,000 sq. ft., is

the best technic for using DDT. In the North Dakota report quoted above,[5] a 10 per cent dust was found only partly effective against flies in livestock barns, so that it became neces-

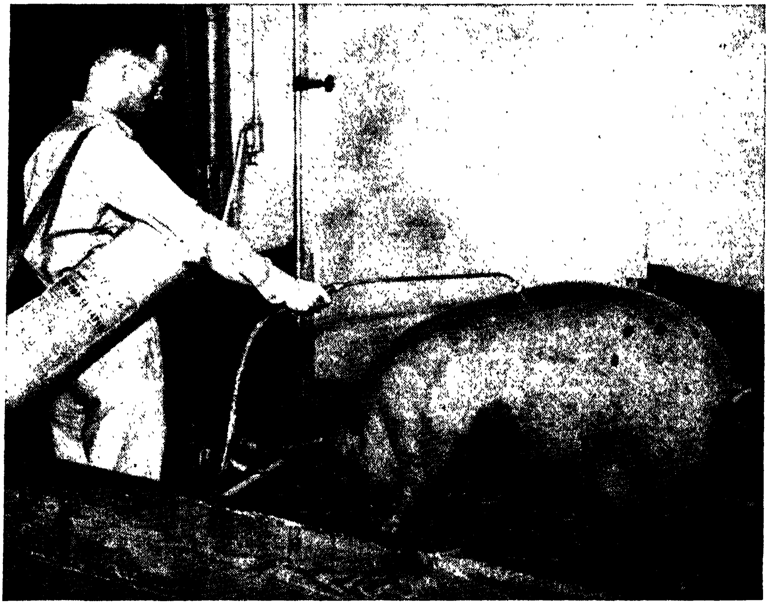

FIG. 7.—DDT on the farm. DDT—in water-based or dust forms—may be used directly on animals for the control of various insect pests. In this case, a United States Department of Agriculture entomologist is applying the 5 per cent water suspension to a sow for fly control. (*Courtesy of U.S. Department of Agriculture.*)

sary to resort to a fly spray at milking time. But when 1 pt. of 25 per cent DDT concentrate in 20 gal. of water was applied to a hog-barn interior, "flies began falling to the floor and in 24 hours the number averaged 45 dead flies per square foot of floor surface." The effect lasted more than 1 month, until the fly season ended. The observers reported that the

herdsman had called attention to the disappearance of raw patches behind the ears of the hogs, apparently caused by the stable fly. They were also impressed with the effectiveness of the DDT against the bloodsucking species, such as the stable fly and horn fly which will not normally enter a flytrap.

Horn Fly. One of the more annoying insects around cattle is the horn fly, a small insect perhaps half the size of a housefly but with a vicious bite. Sometimes as many as four or five thousand of them will be found infesting a single animal. A 2.5 per cent spray of water-suspended DDT, applied to horn bases, back of neck, rump, and belly—the fly's resting places—clears them.

By tests [9] in Kansas, Texas, and Florida, the relief lasts 10 to 15 days, if about 1 qt. is applied per animal. Livestock may also be dipped in emulsions or suspensions [9, 10] not exceeding 0.25 per cent DDT. Oil solutions should not be applied to animals, though some exceptions involving small amounts seem to have been made without harm. Stable flies are more resistant than horn flies, but are effectively controlled; in Florida a 0.2 per cent emulsion on marine grass at the rate of 2 gal. per 100 sq. ft. killed the newly hatched young. DDT was not successful when applied to wet soil against the larvae and pupae of deer flies (*Chrysops* spp.) in Oregon, but when heavy doses were applied to ears of cattle the flies were killed in 12 hr. after they had bitten.

An enthusiastic report from Kansas and Missouri in a farm paper (*Farm Journal*, August, 1945) on the use of DDT for flies and lice, using 0.2 per cent solution (probably a suspension) on the animals, claimed astonishing results. One dairyman said his shorthorns gave 15 per cent more milk after DDT had rid them of flies. Spraying of barns killed not only

flies and moths but the grain beetles hiding around feedboxes. The report was a freehand version of the results of work done by the Livestock Loss Prevention Board, Kansas State Live-

FIG. 8.—DDT on animals. For the control of fleas and certain ticks on dogs and other pets, except cats, DDT should be used in powder form. Dusting the 10 per cent powder through the animal's hair will rid it of fleas, though fleas may become extremely active for a brief period after application. Sometimes it is sufficient to dust the powder around the neck, behind the ears, and along the spine for flea control. Cats are likely to swallow enough of the poison to be harmful because of their habit of licking themselves. (*Courtesy of U.S. Department of Agriculture.*)

stock Sanitary Commission, Kansas State College and U.S. Department of Agriculture, in cooperation with DDT manufacturers.

A similar county-wide test was staged in Orange County, Fla., in August, 1945. Some fifteen thousand cattle were sprayed with a 2.5 per cent water suspension of DDT, and another thousand or so were dipped in a 0.025 per cent solution.

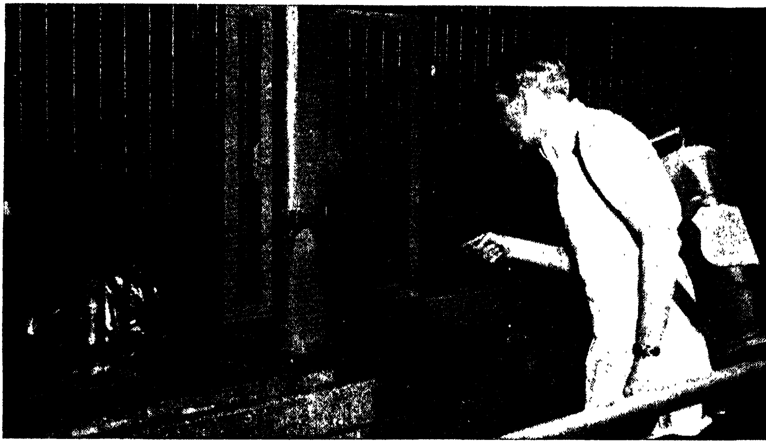

FIG. 9.—DDT in institutions. DDT may be used in many special instances for insect control. The picture shows its use around animal cages in a zoo, where the 5 per cent solution cuts fly infestation. (*Courtesy of U.S. Department of Agriculture.*)

The objective was the control of flies, principally the horn fly, which sometimes in that area infests cattle to the extent of four or five thousand a head. The strategy was to utilize DDT's long action to kill off all flies over a period of perhaps 3 weeks, a little longer than their life cycle, in the hope that, by wiping out all existing adults and the newly hatched flies as they appeared, the infestation could be eliminated for the remainder of the season.

The experiment, by early local reports, was a success. The flies were practically eliminated, and veteran cattlemen re-

marked on the fact that their cattle were standing still or lying down, completely relaxed, instead of moving nervously about switching their tails. There was some increase in milk production, and in a number of barns which had also been sprayed at the same time thousands of cockroaches died. Local reports also said that the mosquito population was sharply reduced as well.

Another angle of the fly problem was touched on in a Delaware report [6] regarding maggot-infested poultry droppings. The maggots were those of flies (*Musca domestica* L. and *Themira putris* L.). Phenothiazine, 25 per cent DDT dust, thiourea, and borax applied to the material left high fly counts, though they were well below untreated checks. But when a 5 per cent DDT oil solution was applied, the flies emerging per 0.25 cu. ft. dropped to zero. A 25 per cent DDT dust and a phenothiazine-lime 1:5 dust gave the best results under turkey sun porches. A 2 per cent DDT deodorized-kerosene solution on the walls of a poultry-killing room gave 100 per cent fly mortality for a month, while a 3 per cent solution on the walls and ceilings of a poultry laying house cut the flies to 8 per cent for 6 weeks.

In a Minnesota report [7] it was recorded that two sprayings of 18 gal. per 5,000 sq. ft. of barn surface kept the barn free of flies all summer. The sprayed material was identified as a 2 per cent suspension of a 20 per cent dust.

Depluming mite (*Cnemidocoptes gallinae Raill.*). In a Minnesota test [7] on chickens badly infested with depluming mites, both henhouse and birds were dusted with a 5 per cent DDT dust. "After two weeks," the report said, "the treated chickens were almost completely free of the mites and began

to put on new feathers. The second application completely rid the birds of the pest."

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Chapter VII

AGRICULTURE

THE value of DDT in agriculture is still under test. That it is a valuable insecticide is definitely established. There is no doubt that it has already made a place for itself among the most important insecticides. It can control more pests than any other single insecticide, and it controls some against which the farmer was almost helpless previously. Whatever the research men find out about it from now on, it can be suggested, will only enhance its standing.

However, it will never displace all other agricultural insecticides, though it might easily become the principal one. For one thing, it will not kill all insects important in agriculture. A U.S. Department of Agriculture report of March, 1945, recounting tests against 170 insects, listed 30 as those against which DDT was "especially toxic" and "definitely more effective than those [insecticides] currently used," named 19 others against which it was "about equal to those ordinarily used" and added 14 more against which it had "little or no effect." The figures, however, mean that there are 49 insects that succumb to DDT—including some household pests already discussed. And many insects have been added to the list since then.

It might be well to recall here the warnings summed up in Chapter III regarding the possibilities of polluting human or animal food through injudicious use of DDT. A statement issued by the Agricultural Research Administration of the U.S. Department of Agriculture, March 27, 1946, reiterated these warnings and pointed out that, while DDT shows great promise against a number of important insects, "the yellow light is on" for these insects for at least one more season.

The statement set no restrictions on use of DDT for such purposes as clearing susceptible insects from forest and shade trees, cotton crops, seed crops, stored seed, and nonfood crops, but made no recommendations (except for cabbage) as far as other vegetable, truck, and fruit crops were concerned. This was surprising, for the statement itself also pointed out that there is no danger in its use on potatoes,— which is also true at least of most other tuber or root vegetables, as well as others. It noted, however, that additional information regarding plant injury and proper formulas is desired.

On the other hand, the report for the year ending June 30, 1945, of the Bureau of Entomology and Plant Quarantine [43] of the same administration said:

> Although residues of DDT on harvested fruit have been found difficult to remove, they do not appear to present a serious problem, because the dosages necessary to give effective control will probably not leave residues on harvested fruit heavy enough to be considered dangerous to human health.

In addition a number of state departments of agriculture have not hesitated to make specific recommendations, on the basis of tests by other than federal research men. It seems

clear that dusts and water suspensions will be the principal formulations to be used in agriculture and in rather light doses, unless fog applications are worked out successfully for large-scale use, and that the likelihood of plant damage, except to cucurbits, is small.

In the following pages, dosages have been given as they appear in the U.S. Department of Agriculture reports. It should be said, however, that some of the formulations listed for sprays seem to be higher in DDT content than necessary in the light of later work. Also, no effort has been made to list all the various plants on which each insect is found. The reports are presented both by crops and insect groups, reflecting the lack of uniformity in the originals.

COMPATIBILITY. The question of mixing DDT with other agricultural insecticides, with fungicides, and with fertilizers, to learn whether it might be applied with them in one operation to supplement its deficiencies, has been checked by U.S. Department of Agriculture chemists. These tests followed the discovery that DDT in alcoholic solution readily reacts with alkalies and that certain substances act as catalysts to promote the decomposition of DDT. What happens is that one hydrogen atom and one chlorine atom are knocked off the DDT molecule, leaving hydrochloric acid, water and 2,2-bis-(parachlorophenyl)-1,1-dichloroethane. The last, representing the remnant of the DDT molecule, has little insecticidal activity. Omitting more technical details and summing up the results of their tests:

Insecticides. "Commercial grades of sodium fluoride, sodium fluosilicate, cryolite, Paris green, calcium arsenate and lead arsenate showed no catalytic activity in decomposing

DDT. Likewise, pure rotenone and pyrethrum were found to be inactive."

Nicotine, however, produced a reaction which should be checked under field conditions.

Fungicides. "Commercial lime-sulfur and 2,3-dichloro-1,4-naphthoquinone showed no catalytic action. With mixtures of DDT and ferric dimethyl dithiocarbamate 0.05 mole of hydrochloric acid was evolved. With Bordeaux mixture 0.04 mole and with sulfur 0.07 mole were obtained."

Fertilizers. "The following fertilizers showed no catalytic activity: Ammonium sulfate, monoammonium phosphate, ammoniated superphosphate, ammonium nitrate, Cyanamid, manure salts, potassium sulfate, Uramon, dicalcium phosphate, double superphosphate, sulfate of potash-magnesia, potassium chloride, sodium nitrate, steamed bonemeal, Milorganite, and mixed fertilizers No. 1 (8-8-8), No. 2 (8-12-16), No. 3 (5-10-5), No. 4 (4-12-4), No. 5 (4-10-6) and No. 6 (3-9-6).

"Dolomitic limestone was the only fertilizer tested which showed catalytic activity."

Another federal report [18] described tests in New Jersey against the Japanese beetle which "indicated that the duration of effectiveness of DDT may be reduced" when it is mixed in tanks with Bordeaux mixture, wettable sulfur, lime-sulfur or tank-mix copper phosphate, but not with ferric dimethyl dithiocarbamate.

Plant Damage. DDT is apparently effective (though some reports differ, as usual) against miscellaneous insects attacking plants of the cucurbit family: the gourds, squashes, cucumbers, melons, pumpkins, etc.

However, most of the reports, no matter how enthusiastic over the efficiency of DDT's control of insects, refer to the damage DDT does to the plants. In some cases they are killed, in others stunted and poor yielding. It is apparent that this family, for some reason, is hypersensitive to the poison, and, unless we learn more about it or devise some way to use it without damaging the organism, it is probably better not to use DDT on plants of the gourd family. Since some of the squash insects appear on other plants, the evidence may be briefly reviewed nevertheless.

In Florida [2] various concentrations of DDT dust down to 0.6 per cent killed from 90 per cent to 100 per cent of fourth instars of the melon worm (*Diaphania hyalinata* L.) on pumpkin foliage within 2 days. A dust containing 0.96 per cent rotenone killed only 36 per cent. A DDT spray killed 100 per cent in 4 days. It was the same story with the pickleworm (*Diaphania nitidalis* Stoll.). In California [14] a 10 per cent dust left only 12 squash bugs (*Anasa tristis* Deg.) alive after 13 days in a small field test, while untreated plots had 221, 20 eggs, and 7 nymphs. In Virginia a 3 per cent dust [25] gave "very promising results" against both insects. In South Carolina [8] a 3 per cent dust applied at 30-day intervals kept 88.9 per cent of 790 fruits free of pickleworm on squash plants, while of 901 picked from untreated plants 27.5 per cent were wormy. In cantaloupe plots dusted four times, only one of 358 cantaloupes was damaged by the pickleworm and none by the granulate cutworm (*Feltia subterranea* F.), while of 359 untreated cantaloupes, 12 were attacked by the pickleworm and 105 by the cutworm. In Nebraska [15] a 3 per cent DDT dust and 35 per cent cryolite dust gave equally satisfactory control against the cucumber beetles (*Diabrotica duo-*

decimpunctata F. and *Duodecimpunctata vittata* F.), and the DDT was better against the squash borer (*Melittia satyrini formis* Hbn.), but the young squash plants were severely stunted by DDT, the acorns being more susceptible. Young pumpkin plants were severely stunted and young cucumbers stunted to some extent. In Texas [10] three applications of 3 per cent dust were ineffective against melon aphids, while it "was very promising" against melon worms and "no burning of plants resulted." It was not very effective against squash bugs.

But in Virginia [17] heavy applications of 2 per cent dust weekly killed squash plants. In Maryland [28] DDT was "not satisfactory" for squash bugs, owing to low kill and irregular performance, while "marked terminal and marginal injury of the plants was evident" after 24 hr. for all concentrations above 1 per cent DDT in xylol-Triton sprays. In New Jersey [26] a 3 per cent dust and a spray gave outstanding control of beetles and fair control of squash bug and was comparable to 1 per cent rotenone against the squash borer, but it caused severe plant injury to young acorn squash, cantaloupe, and cucumbers, and it reduced the yield of Hubbard squash.

On the other hand, in Kansas [29] it completely controlled the striped cucumber beetle, keeping the vines producing until late summer, "an unheard-of condition previously," and the squash bug, increasing the growth of yellow summer crookneck squash, scallop or pattypan, and zucchini squashes. It also controlled the squash borer. In various places, as was to be expected, it was useless against the melon aphid (*Aphis gossypii* Glov.).

There is some indication that DDT may also act as a plant-growth stimulant. A report to the Wisconsin Acad-

emy of Sciences, Arts and Letters, by T. C. Allen and R. Keith Chapman of the University of Wisconsin, indicated that plants stunted experimentally with high concentrations of DDT were also stimulated by low dosages. Since it was possible that the stimulation resulted from the removal of insects, tests were made on insect-free plants. Concentrations giving maximum stimulation were found to be far below the effective insecticidal dosages for cucumber and squash (already known to be susceptible to DDT damage), approximately equal for bean, and higher for carrot and potato.

Successful Uses of DDT

GRASSHOPPERS. The major tests for grasshoppers made by the U.S. Department of Agriculture, on tall alfalfa in Arizona and Wyoming in May, 1944, showed that the pests are "highly susceptible" to DDT, whether it is applied as dust, spray (water suspension), or aerosol.[1]

Various concentrations of dust were used (25, 20, 15, and 10 per cent in pyrophyllite), and it was blown onto the vegetation—alfalfa, Johnson and Bermuda grass, and ditchbank weeds—at varying rates. The grasshoppers present were principally *Melanoplus mexicanus* (Sauss.), *Melanoplus bivittatus* (Say), and *Melanoplus femur-rubrum* (Deg.). All responded with equally sharp reactions to DDT.

The report indicated that 20 lb. per acre of 20 or 25 per cent DDT in pyrophyllite, as dust, will practically eliminate the grasshoppers, even in the tall vegetation. Lower concentrations, *e.g.*, 14 and 20 lb. per acre of 15 per cent dust, reduced them to noneconomic numbers, and it was the observer's belief that the 15 per cent dust at 15 lb. per acre

would be sufficient, if it were well distributed with a multiple-outlet power duster. The effects lasted 1 week without high wind or heavy rain. Kills ranged from 80 to 100 per cent, plus many beetles and crickets, but no bees were found dead.

The sprays were done with the same material suspended in water containing a spreader. Evaluating the various concentrations, the investigators concluded that 15 and 20 per cent DDT in pyrophyllite in water at the rate of 20 lb. of the dust in 100 gal. of water, plus 1 oz. of spreader, will cut the grasshopper population to noneconomic numbers. The killing action of the spray was slower than that of the dusts, but it lasted for weeks. Again no dead bees [34] were found, though there were numerous dead field crickets (*Gryllus assimilis* F.) and carabid beetles. No trace of foliage injury was found, though the spray remained in place for several weeks.

Aerosol bombs killed grasshoppers, but not so effectively as dusts and sprays. The investigators concluded that DDT "in some form seems to offer the most promise of controlling grasshoppers in seed alfalfa and other tall, dense vegetation. It is the only material tested thus far which has killed high percentages of grasshoppers without injuring the vegetation."

In laboratory cage tests, DDT as a bait mixed with wheat bran was not so effective as sodium fluosilicate, however. Sodium fluosilicate, 4 lb. to 100 of bran, killed 100 per cent in 3 days. DDT at the same rate killed only 57 per cent. However, when the DDT was first dissolved in acetone so as to give a better mixture with the bran, its kill rose to 83 per cent.[2] In another report [3] a 50 per cent dust, mixed at the rate of 3 lb. per 100 lb. of wheat bran-sawdust, in one field experiment killed at about equal efficiency with 1 qt. of sodium arsenite solution (32 per cent As_2O_3) in green vegeta-

tion and with 1½ qt. of the sodium arsenite in sparse alfalfa stems and matted dry grass. The same report added that in another field test the DDT was 24 per cent more effective than 3 lb. of sodium fluosilicate in green alfalfa and 13 per cent less effective in dry alfalfa.

CHINCH BUGS. Four reports are available on the use of DDT against the chinch bug (*Blissus leucopterus* Say), three favorable, one adverse.

Two laboratory tests showed that a film of 3 per cent DDT dust on the bottom of a cage containing 50 chinch bugs killed all of them in 6 hr.[4] and that dusts must be applied heavily to give good control, with adults more susceptible than nymphs.[5]

Near Lafayette, Ind., barrier lines of dust containing 5 per cent or more of DDT in pyrophyllite applied at the rate of about 1 lb. per rod, "gave excellent protection of corn from immature chinch bugs migrating to it on foot from adjacent wheat." It did not repel them or prevent them from reaching the corn, it was found, but killed them before they were able to do material injury. The same investigators found that heavy applications of 1 to 5 per cent dusts in pyrophyllite to infested portions of corn plants and the soil near by "gave excellent control" without injury to the plants.[6]

At Urbana, Ill., a group of investigators decided that DDT is toxic to chinch bugs, but its action is slow and not comparable to dinitro-*o*-cresol. They collected adult and fifth-instar chinch bugs and checked the mortality after the bugs had walked through various dust barriers. In 1 hr. 1 per cent dinitro-*o*-cresol gave 100 per cent mortality, while DDT in 24 hr. gave 33 per cent and pyrophyllite alone 26 per cent. In another test, they dusted large numbers of the insects in glass jars with dinitro-*o*-cresol, sabadilla, and DDT, in various

concentrations, and estimated the mortalities to the nearest 25 per cent. A 10 per cent DDT gave 90 per cent mortality in 24 hr., while the others reached 100 per cent in 1 to 6 hr., they found.[7]

Potato Insects

COLORADO POTATO BEETLE. The Colorado potato beetle (*Leptinotarsa decemlineata* Say) was, by the original Geigy reports, the first insect against which DDT was found successful. Brought to Europe in food taken there to feed the American Army in the First World War, it had spread and was threatening the whole Swiss crop until DDT saved the day. This pest is a native American, which in pre-Columbian days fed on a plant related to the potato, the buffalo bur, but attacked the potato when it began to be grown in the West. It gradually spread eastward until in 1874 it reached the East Coast. The beetles had gotten to Germany by the Second World War, and the British were accused by Goering of dropping them from airplanes. Most lads brought up on farms not so many years ago remember their summer task of picking them off by hand. They called them potato bugs. The insect is yellow, with 10 black stripes, as its Latin name indicates, and with its larvae, which also feed on the potato plants, it can destroy large plantings quickly if it is not controlled.

Every report indicates that DDT in any of several forms gives "complete protection" from the Colorado potato beetle. Oddly, this is not one of the 30 insects named by the U.S. Department of Agriculture as susceptible to DDT, or even of the 19 others against which DDT is equal to previous insecticides. But the reports speak for themselves.

South Carolina Experiment Station: "Potato plants were completely protected" by a 3 per cent dust.[8]

Raleigh, N.C.: A 3 per cent DDT dust was "very effective" in controlling both larvae and adults. "It was far superior to other insecticides used, including cryolite, a 1 per cent dinitro-o-cyclohexylphenol dust with sulfur as a filler, and a proprietary brand of calcium arsenate plus a copper fungicide." A 1 per cent DDT dust was better than the other dusts but not so good as 3 per cent DDT, they found. A water suspension of DDT was not effective.[9]

Texas: A 3 per cent DDT talc-diluted dust "gave complete control of both adults and larvae." They did not reappear for the 10 days of the study.[10]

Wisconsin: In a laboratory test, using a water suspension of DDT at the rate of 0.8 lb. per 100 gal. in a fly spray, investigators found that the poison had hit all of 10 larvae used when the test was checked in 16 hr., and that five were dead and five on their backs kicking slowly, with only a little foliage destroyed. On a control plant with 19 larvae, 18 were alive and all foliage was eaten.

In an Oklahoma laboratory test [5] with a 3 per cent dust, a 24-hr. check showed 74 per cent control.

In Minnesota field tests [12] the beetle "was killed with remarkable ease" in the adult and nymphal stages within 24 or 36 hr. after dusting with dusts ranging up to 5 per cent.

It was concluded:

> On the basis of these experiments, it is apparent that DDT proves to be one of the outstanding insecticides for the control of most of the potato insects, confirming the previously reported results.
>
> From two years of experiments, it is evident that, while

> DDT has a considerable residual value on foliage under field conditions, it certainly does not possess very long residual properties outdoors as compared with indoor experiments.
>
> The combination of DDT with 5 per cent of yellow copper oxide, as a rule, gave quite consistently somewhat more effective control of most of the potato insects than the same concentrations of DDT alone.

A number of other potato-infesting insects are similarly susceptible to DDT, and we may as well discuss them at this point.

POTATO LEAF HOPPER (*Empoasca fabae* Harr.). More than a dozen reports give full assurance of the ease with which DDT controls this pest. At Columbus, Ohio,[13] a 1 per cent DDT dust in 19 per cent Bancroft clay and 80 per cent sulfur was found "as effective as a 0.025 per cent pyrethrum-sulfur mixture, though most of the leaf counts for DDT were definitely lower." Neither sulfur undiluted nor Bordeaux mixture in a spray (details unreported) was as effective as DDT.

In Wisconsin a 2.5 per cent DDT dust reduced infestations on potatoes and beans 78 to 99 per cent in 1 to 3 weeks after dusting, and the DDT dust "gave a greater reduction in leafhopper populations than did a dust mixture containing 1 per cent of dinitro-*o*-cyclohexylphenol and 50 per cent of sulfur." [14] In Columbus, Ohio, tests, reported in the same compilation, "DDT sprays and DDT-sulfur dusts gave better results" than did the dinitro mixture or a pyrethrum-sulfur mixture containing 0.025 per cent of pyrethrins and 50 per cent sulfur. The DDT sprays contained up to 0.08 per cent of DDT in a kerosene emulsion, and the dust mixtures consisted of 1.4 per cent of DDT, 50 per cent of sulfur, and the remainder pyrophyllite.

In North Carolina,[9]

> . . . plots treated with the 3 per cent DDT dust for the control of flea beetles and leaf hoppers yielded more potatoes than did any of five other differently treated plots. Yields from plots treated with a dust mixture of dinitro-o-cyclohexylphenol and cryolite were second best.

In New Mexico, tests showed[15] "significant reductions" of leaf hoppers from either 3 per cent dust or a spray of 4 lb. of 10 per cent DDT dust to 100 gal. of water. Heavily infested plots were treated three times at 2-week intervals with 1 per cent dust.

> Within 12 hours after the first treatment, leaf hopper populations were reduced to a relatively insignificant level, and this condition was maintained for two weeks even in the presence of frequent heavy rains. Foliage on the treated plants remained green, and the plants matured at the normal time, whereas foliage on the untreated plants was largely dead two weeks earlier. An increase in yield of approximately 265 per cent was obtained.

In Ohio tests,[16] a water-dispersible DDT composition 25 per cent active was sprayed in field tests at 4 lb. to 100 gal. of water (equal to 1 lb. of DDT) without a spreader, at 10-day intervals, at the rate of 200 gal. to the acre. "The remarkable effectiveness of DDT in controlling the potato leaf hopper, in influencing leaf character and in increasing yields was exhibited in these experiments," the report read. Counts showed the hopper populations reduced to zero after either DDT alone or with various fungicides. Yield figures were interesting: Untreated plots, 316 bu. per acre; after Bordeaux mixture, 477; DDT, 571; Bordeaux-DDT, 589; COC-S, 480; COC-S-DDT, 570; Fermate-DDT, 599.

POTATO FLEA BEETLE (*Epitrix cucumeris* Harr. *et al.*). Numerous reports testify to the value of DDT, especially in dust form, against the potato flea beetle and the tuber beetle (*Epitrix tuberis* Gentn.), the western potato flea beetle (*Epitrix subcrinata* Lec.), and the spotted cucumber beetle (*Diabrotica duodecimpunctata* F.), all of which damage tubers.

A Washington report [14] found that 10 per cent DDT dust at the rate of 17 lb. per acre produced only 42 per cent damaged tubers, compared to 54 per cent for a 70 per cent cryolite at 10 lb. per acre, but the marketable yield from the two fields was about the same. The infestation was of the tuber and Western flea beetles.

A Minnesota report [12] on its use against *Epitrix cucumeris* said that as little as a 1 per cent dust would give effective control, with nearly complete mortality in 24 hr..

From Oregon, after elaborate tests, a definite recommendation was made [24] that DDT (3 per cent dust) be used on potatoes for the control of the tuber flea beetle and the spotted cucumber beetle. It added that there can be no doubt that the larvae of the cucumber beetle cause injury to potato tubers similar to and as severe as the tuber flea beetle.

Two other reports were less enthusiastic. One [25] found DDT equal to calcium arsenate. The other [26] found it equal to calcium arsenate or cryolite at the same dosage, but not in kill to calcium arsenate-Bordeaux mixture (2-4-6-50), though the DDT-treated areas gave as high a yield.

OTHER FLEA BEETLES. Several other reports of the use of DDT against flea beetles are in the literature.

It controls the corn flea beetle (*Chaetognema pulicaria* Melsh.).[6] A 0.66 per cent spray (10 per cent dust, spreader,

water) repeated five times 3 to 6 days apart left only about two beetles to the row compared to 128 on checks. It also controlled the bacterial wilt transmitted by this insect.

A North Carolina report [14] said that a 5 per cent dust gave 66 per cent control from the first application and 59 per cent from the second, compared to 39 to 54 per cent for a 60 per cent cryolite dust for the tobacco flea beetle (*Epitrix hirtipennis* Melsh.).

A striped flea beetle, otherwise unidentified, on turnips in Texas was controlled by a dusting with 3 per cent DDT. The young plants averaged 20 per plant before the dusting and there were none 2 days later.[10]

An Indiana report [23] of the use of DDT on eggplants against unidentified flea beetles said that one dosage with a 20 per cent spray "appeared to have no effect."

As many of the above insects, such as the spotted cucumber beetle, the potato and tobacco flea beetle, and the Colorado potato beetle, belong to the family Chrysomelidae, the family thus appears generally susceptible to control by DDT.

Cotton Pests

Cotton, one of the more important crops of the nation, is also one which seems especially infested with insects, two of which, the white-fringed beetle (*Pantomorus leucoloma* Boh.) and the pink bollworm (*Pectinophora gossypiella* Saund.) have hitherto been extremely difficult to combat. DDT kills both. However, it has not proved effective against the familiar cotton-boll weevil (*Anthonomus grandis* Boh.), nor the cotton-leaf worm (*Alabama argillacea* Hbn.).

THE WHITE-FRINGED BEETLE. Tests reported during 1944 from the U.S. Department of Agriculture laboratories at Florala, Ala., brought the unqualified pronouncement that DDT "was the most potent insecticide ever tested against adult white-fringed beetles." [19] This pest, a native of South America first seen in Florida in 1936, works somewhat like the Japanese beetle, its larvae chewing up roots in the soil, the adults destroying plants above ground. It attacks not only cotton, but also peanuts, yams, chrysanthemums, and many other plants in the Gulf States. It does not fly. There are no males, so, although its expansion is slow, one beetle can start an infestation.

In one test 2.5 per cent DDT dust at the rate of 0.29 lb. of actual DDT per acre gave 73 per cent mortality on peanut foliage, and, at 0.39 lb. per acre, 94 per cent mortality on chrysanthemum foliage. The rates amount to 11.6 lb. of 2.5 per cent DDT-pyrophyllite on peanuts and 15.5 lb. per acre on chrysanthemums. A synthetic cryolite (sodium fluoaluminate 76.8 per cent) gave 39 per cent and 55 per cent mortality. From these and other tests the investigators concluded that DDT as a stomach poison in dust form was 69 to 74 times as toxic to white-fringed beetle adults as sodium fluoaluminate. In sprays, ⅛ lb. of DDT per 100 gal. (about 1 lb. of 10 per cent dust) plus 1 oz. of wetting agent, gave 92 per cent mortality, about the same as 8 lb. of cryolite.

On the soil surface, applied at the rate of 18.6 lb. of 5 per cent dust (equal to 0.93 lb. of DDT), the DDT gave 84 per cent mortality for the beetles in 96 hr. and 94 per cent in 168 hr., compared to a maximum of 5 per cent for cryolite. (The beetles move to the soil surface to oviposit or rest, spending more time there than on vegetation.)

PINK BOLLWORM. This insect is the larva of a moth, itself harmless, which entered this country in 1915 or 1916 from Mexico, and which has been prevented from ruining American cotton only by the most energetic battles in Texas, Florida, Georgia, New Mexico, and Arizona. Says one authority: [20] "It is considered that the only reason why the United States can still compete in the cotton markets of the world, in spite of higher labor costs, is that we are the only large-producing country that still enjoys the absence of the pink bollworm." The larva has an unfortunate habit of entering the cottonseed, and it was in that vehicle that it moved from its original home in India to Egypt, and thence to Brazil, Mexico, and other countries.

Says a U.S. Department of Agriculture report: [21] "The results [of tests with DDT] against the pink bollworm were especially encouraging, since no satisfactory insecticidal control for this insect was previously known."

Eight applications of 10 per cent DDT dust (pyrophyllite) at 15 lb. per acre gave an 88 per cent reduction in the larval population of the bolls, compared to 44 per cent for areas dusted with cryolite. In another test on a 3½-acre field, the control area, untreated, had 12 worms per green boll, but the areas receiving eight applications of dust had an average of 0.73 worm per boll, a reduction of 94 per cent. The field was 35 per cent infested before the dusting began. Airplane spraying of cotton with DDT is also being tested successfully.

COTTON BOLLWORM (*Heliothis armigera* Hbn.). This is the insect also familiar as the corn-ear worm and the tomato fruitworm, the larva of a small brown moth. To the cotton growers of the country, it is a persistent and expensive pest.

The U.S. Department of Agriculture reports: "DDT was effective against the bollworm."[21] Field tests at Waco, Tex., showed that two dust applications at 16 lb. per acre had given gains of seed cotton per acre of 148 lb. from 1 per cent DDT, 154 lb. from 2 per cent DDT, 238 lb. from 4 per cent DDT, and 230 lb. from 8 per cent DDT, and 273 lb. from calcium arsenate at the same rate. However, tests on caged cotton plants with dusts showed a mortality of third-instar bollworms of 84 per cent for 4 per cent DDT dust compared to 73 per cent from a 1:1 mixture of basic copper arsenate-sulfur, both at 16 lb. per acre, compared to 62 per cent for calcium arsenate, 65 per cent from lead arsenate, and 66 per cent from cryolite, each at 8 lb. per acre. Water sprays at the rate of 1.28 lb. of DDT per acre brought 100 per cent mortality, and at 0.64 lb. per acre, 89 per cent, ranging down from there.

In a large experiment at Bryan, Tex., four dustings with 4 per cent DDT-pyrophyllite at 16 lb. per acre gave a gain of 736 lb. of seed cotton per acre, compared to 688 for calcium arsenate.

Cotton Flea Hopper (*Psallus seriatus* Reut.). Texas tests[21] showed not only that DDT will control the cotton flea hopper, but that it is "about equal," as far as reducing the insect population goes, to the standard 1:2 calcium arsenate-sulfur mixture hitherto used. However, "yields were significantly better" from 2 per cent DDT applied five times at 12 to 13 lb. per acre in heavily infested plots than from the 1:2 calcium arsenate-sulfur or from weaker DDT dusts.

Investigators have also found that 2.5 per cent and 5 per cent DDT dust, applied once, produced about one-third greater reduction in insect population in heavily infested plots than did the calcium arsenate-sulfur mixture, and it lasted

longer. In still other tests "no significant difference" was found among 4 per cent DDT, 2 per cent DDT, DDT-pyrophyllite-sulfur (2:18:80), calcium arsenate-sulfur (1:2), DDT-pyrophyllite plus (1:2) calcium arsenate-sulfur (2:18:80), all applied four times. "The yield from each treatment was greater than from the check," the report [21] read, "and from the 2 per cent DDT-pyrophyllite significantly greater than from the calcium arsenate-sulfur, but not significantly better than from the other treatments containing DDT." A Texas test [10] found that a 3 per cent DDT dust applied once at 12 lb. per acre gave 77 per cent control the first week, 36 per cent the second week, and 34 per cent the third week—better than either sulfur or sabadilla.

LYGUS BUGS. STINKBUGS. Both caged-plant and field tests have been made on these insects in Arizona and Louisiana.[21] They include *Lygus oblineatus Say* (the tarnished plant bug), *Lygus* spp., two other mirids (*Adelphocoris superbus* Say and *Creotiades femoralis* Van Duzee), and several stinkbugs (*Chlorochroa sayi* Stal, *Chlorochroa ligata* Say, *Euschistus impictiventris* Stal, and *Thuanta custator* F.). The caged-plant tests showed a high mortality, but the field-test results were "somewhat erratic," and control was not so consistent.

In one Louisiana field test, control of the tarnished and rapid (*Adelphocoris rapidus* Say) plant bugs was poor despite six dustings with 2.5 per cent and 5 per cent DDT. Arizona tests showed that DDT-sulfur dust at weekly intervals gave better control of mixed insect populations than did arsenical-sulfur mixtures. Another produced a report that seven applications of DDT-pyrophyllite-sulfur (4:36:60) showed a gain of 1,018 lb. of seed cotton per acre, 42 per cent more than the check, compared with 13 to 26 per cent for four arsenical-

sulfur mixtures. An 18-acre field dusted six times by airplane with the same DDT mixture showed a gain of 920 lb. of seed cotton, 97 per cent more than the check and 30 per cent more than an adjacent 58-acre field dusted with Paris green-sulfur (15:85). In a fourth test three 1-acre plots dusted seven times by power duster produced 551 lb. gain, as compared with 396 lb. from Paris green-sulfur (7.5:92.5) and a loss of 22 lb. from dinitro-*o*-cresol 1 per cent. DDT dusts used included 2 per cent DDT-pyrophyllite for two applications, DDT-pyrophyllite-sulfur (4:36:60) for three, and 5 per cent DDT-pyrophyllite for two.

A California report[40] pronounced a 3 per cent dust "very effective" in controlling Lygus bugs on alfalfa seed, adding that the results were "so promising" that more study was strongly recommended. The dusted area, it was estimated, would have yielded 400 lb. of seed against 150 for an undusted check, though heavy rains which caused rotting and germination spoiled the harvest. Two applications of the dust were made at the rate of about 28 lb. per acre, and the Lygus bugs dropped down 79 to 90 per cent during the height of the season.

MISCELLANEOUS INSECTS ON COTTON. A 2 per cent dust "gave excellent results" against the beet army worm in Arizona.

A 2 per cent dust gave a 100 per cent kill in 67 hr. in Arizona of a small darkling beetle (*Blapstinus auripilis* Horn).

A spray (0.5 lb. DDT, 3 pt. raw linseed oil, 100 gal. of water) applied at the rate of 58 gal. per acre "gave good control" of the velvet-bean caterpillar (*Anticarsia gemmatilis* Hbn.) on velvet beans.[22] A second application protected new foliage. The velvet-bean caterpillar, which attacks cotton, soybeans,

peanuts, and other plants as well, is one of the insects against which DDT is especially toxic. A 3 per cent dust has also been found effective on peanuts and soybeans.[6]

NOTE AND WARNING. Every test so far made has shown that DDT is not effective against four major cotton pests:

The cotton-boll weevil (*Anthonomus grandis* Boh.)
The cotton-leaf worm (*Alabama argillacea* Hbn.)
The cotton aphid (*Aphis gossypii* Glov.)
The red spider (*Tetranychus* sp.)

As a matter of fact, on cotton, as on other plants, DDT produced an increase of aphids and red spiders, as do certain other insecticides.

Cabbage Family Pests

Plants of the cabbage family have a number of major insect pests. Besides the various aphids and mites, the most menacing are the cabbage looper (*Autographa brassicae* Riley), the imported cabbage worm (*Pieris rapae* L.), and the larva of the diamondback moth (*Plutella maculipennis* Curt.). The cabbage webworm (*Hellula undalis* F.), the corn-ear worm, and several of their cousins (*Agrotinae* spp.) are also mentioned.

DDT controls the looper, the imported cabbage worm, and the diamondback larva, by several reports.

A summary[14] covers tests in California, South Carolina, and Louisiana, which found that a 1 per cent dust at 10-day intervals would control all three, and that a 2.5 per cent dust was required for the webworm.

Another South Carolina report [8] told of "perfect control" of cabbage worms with a 3 per cent dust. The same formulation in Texas [10] gave a "complete cleanup" in 36 hr. of a looper infestation averaging five per head. In Wisconsin [27] the 3 per cent dust wiped out loopers in test plots in 24 hr., where rotenone and calcium arsenate failed to do so completely, and the DDT-treated heads were heavier at harvest. It was the same with a spray made with 2 lb. of a 20 per cent dust in 100 gal. of water. DDT, as dust or spray, was "superior to or at least equal to rotenone or arsenicals," the Wisconsin investigators found, and the DDT-treated plants were more vigorous and of a brighter green. Aphids, however, increased.

In Illinois [7] the 3 per cent dust was much better than rotenone against loopers; the head weight averaged 3.6 lb. for DDT against 2.77 for rotenone. In Maryland [28] both emulsion and suspension gave good results. The emulsion consisted of 1 lb. of 20 per cent DDT dust mixed with xylene or triton and 100 gal. of water, while the suspension mixed 2.5 lb. of 20 per cent dust to 100 gal. It was also noted that 39 per cent of their untreated controls had black rot, while the suspension-sprayed cabbages had only 4 per cent so affected, and the emulsion-sprayed none.

In Kansas [29] a 3 per cent dust every 3 weeks completely controlled looper, imported worm, and moth larva and "apparently increased growth slightly" and prevented head splitting at maturity due to renewed growth following rain.

In New Jersey [26] the dust gave "outstanding control" of all three insects and 99.2 per cent control of *Thrips tabaci* Lind in a dichloroethyl ether emulsion. But both in New Jersey and in Washington [24] DDT was not effective against cabbage maggots.

Corn Insects

Two insects especially prominent as pests of sweet or field corn are well controlled by DDT, the U.S. Department of Agriculture has shown. They are the European corn borer (*Pyrausta nubilalis* Hbn.) and the corn-ear worm (*Heliothis armigera* Hbn.), the second of which we have already met as the cotton bollworm.

EUROPEAN CORN BORER. In a study [30] near Toledo, Ohio, a 10.8 per cent DDT-pyrophyllite dust, suspended in water with a spreader at the rate of 4 lb. per 100 gal. on sweet corn, produced 112 clean No. 1 ears per 100 plants and 4 infested ones. A 5 per cent dust in spray and a rotenone spray gave substantially lower results, while the untreated control areas produced 32 clear ears and 83 infested ones per 100 plants. The spray was pronounced "outstanding in control of the borer"; it reduced the borer population from 1,834 per 100 plants to 38 and in the ears from 496 to 4. The spray was applied three times: June 17, with corn 36 in. high and 70 per cent of tassels emerging, June 22, and June 27. About 175 gal. per acre were applied from a wheelbarrow sprayer operated by a gasoline engine with a hand-directed nozzle that produced a solid cone of spray.

At the same time [30] a series of tests with dust was carried out, using 0.75 per cent, 1.5 per cent, 3 per cent, and 6 per cent dusts in pyrophyllite, for four applications, June 18, 25, and 30 and July 5, on sweet corn (Spancross) already infested at the rate of 10 larvae per plant. Application was at the rate of 40 lb. of dust per acre. Borer reduction increased with each increase in dosage.

The check plots produced 1,007 borers per 100 plants. There were 390 more in the ears. The 6 per cent dust gave 91 in every 100 plants and 19 in the ears. The 3 per cent dust gave 277 per 100 plants and 90 in the ears.

Evaluated by production, the 6 per cent dust gave, for every 100 plants, 126 No. 1 and borer-free ears, 15 culled due to borer, and 7 infested but salable. The check gave 20 good ears, 15 salable but infested, and 96 culls due to borer. The other dust mixtures gave various levels in between; all dosages more than doubled the number of salable as well as No. 1 and borer-free ears. No injury or other effect on the growth of the corn was observed. Airplane application of various strengths of sprays and dusts gave irregular results, due to unequal distribution and differing with the varieties treated, and it was regarded as "somewhat less effective" than the concentrated spray.

An Illinois report [7] found a cube (rotenone) spray better than a DDT spray by 80 per cent to 77 per cent control of borers, but found a 3 per cent DDT dust better than a rotenone-nicotine-sulfur mixture by 67.3 per cent control of borers compared to 48.1 per cent, but a 0.025 per cent DDT spray at 175 to 200 gal. per acre applied four times in a third test gave 96 per cent control, reducing borer population from 313.5 per 100 plants to 11.9, with a 0.24 per cent rotenone spray second best with 12.3 per 100.

In New Jersey four applications of 3 per cent dust 5 days apart on sweet corn gave good results: 93.2 per cent control of the first generation and 90.7 per cent for the second, while 1 per cent rotenone gave 83.8 per cent and 83.2 per cent, and 4 per cent nicotine gave 90.8 per cent and 88.2 per cent. The checks produced 1,018 and 818 borers per 100 plants.

The testers noted that the DDT "interfered with the growth" of the plants.

A Delaware report [83] tested a 20 per cent dust in spray, a 3 per cent dust, a calcium arsenate-copper dust in spray, and Bordeaux mixture on potatoes against the potato leaf hopper and the corn borer. The DDT spray (4 lb. 20 per cent dust per 100 gal. of water) cut the borers per 10 potato stalks to zero and the leaf hoppers to four, while the 3 per cent dust gave two and five respectively, the calcium arsenate-copper 11 and 17, and the Bordeaux mixture 24 and 19. Yields were 179 bu. per acre for the DDT spray, 167 for the DDT dust, 146 for the calcium arsenate-copper, and 116 for the Bordeaux mixture. Controls showed 81 leaf hoppers and 23 borers per 10 stalks, with a yield of 110 bu. per acre.

Several similar reports are available.

Corn-ear Worm. An Illinois experiment with 2 per cent DDT dissolved in two highly refined mineral oils and injected into the tips of the ears of dent corn grown for seed brought this conclusion: "Of the four insecticides tested, DDT appears at present to be the most ideally suited for use in controlling the earworm in dent corn grown for seed." [82]

The test involved eight inbred lines of various ear and husk types, for which mineral-oil injections alone had previously been used. The mineral oils were used as solvents for 2 per cent DDT, pyrethrum, dichloroethyl ether, and styrene dibromide. Check plots showed 92.1 per cent ears infested, 19 kernels per ear lost to the worm and disease in green corn and 2.3 kernels lost in maturing corn, and 0.35 larva per ear at harvest. DDT in either oil and in 0.6- and 1.2-ml. dosage per ear gave 14.4 per cent ears infested, 2.7 kernels per green ear lost and 0.04 kernel per mature ear lost at harvest, and

0.01 larva per ear at harvest. Pyrethrum showed 49.3 per cent infested, 11 kernels per green ear lost, 1.1 kernels green and 1.4 kernels mature lost to worms, and 0.32 worm per ear at harvest. Styrene dibromide averaged 51.2 per cent ears infested, 9.7 kernels green and 1.0 mature lost per ear, and 0.24 live worm per ear at harvest.

The investigators observed that in 1944 "by far the greatest saving in corn resulted from prevention of the diseases that enter the ears following earworm attack." The note did not apply to disease which enters through the shank. They pointed out also that the 0.6-ml. dosage did not appear to reduce the development of the tips of the ears appreciably, while the 1.2-ml. dosage caused some loss of tip kernels, especially in the tight-husked line, a loss thought due to the oil,

> . . . as none of the insecticides tested appeared to retard kernel development. DDT was the only insecticide which protected the corn until harvest time. DDT in mineral oil gave almost complete control of the corn earworm in both the green and the maturing corn ears in both experiments. Some of the slight damage shown undoubtedly resulted from larvae already established before the insecticide in oil was applied. In the small-plot experiment most of the damage in the DDT plots occurred in the one inbred line, U.S. 187-2. Pyrethrum, styrene dibromide and dichloroethyl ether were all less effective than DDT. Styrene dibromide ranked second to DDT.

In a commercial-scale experiment, 2 per cent DDT in Superla 13 was injected at the rate of 0.75 ml. per ear in two rows. A 3 per cent dichloroethyl ether solution in the oil at the same rate was injected into the ears on two more rows, and a third pair was left untreated. A total of 56 per cent

of the ears had small larvae established in them before treatment. The DDT rows showed 24.8 per cent infested ears, 2.2 green and 0.5 mature kernels per ear lost, and no living larvae at harvest and took 20 min. per bag to remove damaged kernels. The dichloroethyl ether rows showed 82.3 infested ears, 9.9 and 3.1 kernels per ear lost, and 0.26 worm per ear and took 40 min. per bag to sort. Check rows showed 93.6 per cent infested, 11.5 and 4.3 kernels per ear lost, and 0.23 living larva and took 60 min. per bag.

On sweet corn, the same investigators [31] found equally promising results from DDT. The DDT 2 per cent was both injected into the tips of the ears and atomized over them in an effort to compare the expensive injection method with the cheaper atomization or spray from a small paint gun on corn planted for canning. Enough was applied to wet the silks and upper parts of the ears with little or no runoff. At the same time it was compared with 0.2 per cent pyrethrins in the same vehicles and with a 1 per cent DDT solution.

They found that DDT 2 per cent in Superla 13 alone atomized in three tests gave 92.7 per cent undamaged ears, with 0.17 average larva per ear. DDT 2 per cent with xylene 2.5 per cent and Triton B-1956 1 per cent in one test with two applications gave 94.7 per cent average ears undamaged and no larvae in the ears. No other mixture gave so high a control, with pyrethrins far down the list. They summed up:

> DDT in mineral oil or in an emulsion gave much better control than did pyrethrum. DDT in one emulsion which did not contain oil was somewhat more efficient when injected or with two applications atomized than pyrethrum in straight mineral oil. Although the plots were subjected to showers of rain from two to eight days after the materials

> were applied, good control was obtained by atomization of several of the oil emulsions containing DDT, whereas none of the emulsions containing pyrethrum offered any promise. It cannot be considered, however, that the best type of emulsion or best possible method of application has yet been employed. A part of the damage in ears treated by atomization with DDT apparently resulted from reinfestation by the corn earworm, since most of the larvae observed in the ears at harvest were small. . . .
>
> DDT in an emulsion or oil solution applied by atomization seems very promising for control of the earworm. These tests were preliminary in character, however, and no recommendations for practical farm use can yet be made.

Commenting on this study, a U.S. Department of Agriculture compiler [6] wrote, "The results indicate that one may be found that will give high protection from the earworm when it is atomized on the ears at comparatively low cost and with no injury to the ears or plants."

In southern California [6] 85 to 99 per cent of worm-free ears were produced by injection of white mineral oil containing 1 per cent or more of DDT for the corn-ear worm.

In South Carolina [8] a 3 per cent dust in a test plot cut the infestation to 32.2 per cent in 59 ears compared to 86.2 per cent in 65 untreated ears.

In Texas [10] a 3 per cent dust, applied three times late in May, cut the infestation 50 per cent the first time, 40 per cent the second, and 30 per cent the third.

In Delaware [33] a 3 per cent dust used against the ear worm on tomatoes (where it is called the tomato fruitworm) showed zero injured fruit, as did cryolite in talc, while cryolite in corn meal 1:10 showed 1.7 per cent injured fruit, calcium

arsenate-lime 1:1 showed 1.8 per cent, and the checks showed 2.4 per cent.

In Kansas [29] a 3 per cent dust applied once to the green silk obtained 75 per cent control, whereas the twine method got 100 per cent.

In Maryland [6] "good protection of young sweet corn from the corn flea beetle (*Chaetognema pulicaria* Melsh.) and considerable reduction in the bacterial wilt which it transmits" were obtained from five applications of a DDT spray, obtained by adding 10 per cent DDT-pyrophyllite dust to water and spreader. Only two beetles were found on a treated row, compared to 128 on an untreated one.

"Very effective control" of Japanese beetles attacking silking corn was obtained with 4 per cent dust in Delaware.[33]

Tobacco Insects

DDT has been tested against half a dozen insects affecting tobacco and the work summed up in a U.S. Department of Agriculture report.[14]

Against the tobacco budworm (*Heliothis virescens* F.) in South Carolina a 10 per cent dust gave from 88 to 100 per cent kill in 4 days.

Against the tobacco flea beetle (*Epitrix hirtipennis* Melsh.) a 5 per cent dust gave 66 per cent control following one application and 59 per cent after a second. Three 60 per cent cryolite dusts gave 39 to 54 per cent.

Against the tobacco hornworm (*Protoparce sexta* Johan.) in South and North Carolina neither a 5 per cent nor a 10 per cent dust gave satisfactory control in the field. A 10 per cent dust tried in the laboratory also failed against the fifth

instar of the insect. However, both the fifth and the third instars of the tomato hornworm (*Protoparce quinquemaculata* Haw.) were killed readily on tobacco.

In Peet-Grady chamber tests at Richmond, Va., DDT in 5 per cent acetone-oil solution gave a 97 per cent kill of the tobacco moth (*Ephestia elutella* Hbn.) in 3 days and a 71 per cent kill of the cigarette beetle (*Lasioderma serricorne* F.) in 5 days. A 15 per cent solution gave 98 and 90 per cent kills, whereas a 0.2 per cent pyrethrum oil spray gave 100 per cent and 46 per cent. A 15 per cent solution sprayed on packages of cigarettes did not prevent them from becoming infested during an exposure of 30 days to both insects.

Miscellaneous Insects

We have already made the prediction that DDT will be found to kill many insects beyond the important ones against which specific tests in laboratory and field have shown it to be effective. The reports of such tests frequently contain references to other pests wiped out along with the insects directly aimed at. It is, of course, hard to imagine a powerful insecticide like DDT being sprayed or dusted into foliage on a midsummer's day and not killing more than one type of insect. In fact, it doesn't happen.

When it was used against grasshoppers, for instance, it also killed [1] crickets and carabid beetles. Against the hairy vetch bruchid it also knocked out coccinellids and nabids, flies, ants, and spiders of various species.[6, 37] Against Lygus bugs on alfalfa [6] it also killed coccinellids, nabids, grasshoppers, flies, and lepidopterous larvae. A New Mexico report [15] regarding its use on potatoes has it killing not only leaf hoppers, psyllids,

and flea beetles but also Lygus, aphids, nabids, flower bugs, and coccinellids.

With such data in mind, it is safe to say that the individual user of DDT, the farmer, orchardist, or gardener, striking with it at some specific insect pest will find his crop cleared of others, though some will undoubtedly still remain. There are a number of indications along that line in the records. These expand the prospect of the value of DDT, and it seems justifiable to include them here, with the caution that so far they are not conclusive but only indicate possibilities and show that the insect named is probably susceptible to DDT. In some cases the insect is not even definitely identified.

VARIOUS LEAF HOPPERS. Besides the potato leaf hopper (*Empoasca fabae* Harr.) against which DDT is potent, it has been tested against several other leaf hoppers.

In eleven tests in Idaho, a 5 per cent DDT dust at 115 lb. per acre [18] produced an average cut in populations of the beet leaf hopper (*Eutettix tenellus* Bak.) of 95 per cent in 3 days and 89 per cent after 10 days. A spray containing 4 lb. of DDT dust at the rate of 200 gal. per acre did not give so great a reduction.

In Texas [10] one application of 3 per cent dust at 30 lb. per acre on carrots failed to produce any reduction of the six-spotted leaf hopper (*Macrosteles divisus* Uhler), though cage tests showed a high mortality. In Minnesota [12] three applications of 5 per cent DDT or 5 per cent DDT with 5 per cent yellow copper oxide, both in pyrophyllite, in a large-scale field test, showed that both combinations of DDT "gave very satisfactory results in controlling this insect and in giving a much greater percentage of disease-free carrots as compared

with other plots." The six-spotted leaf hopper transmits a virus disease to carrots which causes serious damage.

Other types of leaf hopper, such as apple and grape, will be considered under fruit insects.

THE VETCH BRUCHID. Hairy vetch, raised in western Oregon for seed because of the difficulty of getting its seed in the South, where it is used as a cover crop, is subject to the attack of the vetch bruchid (*Bruchus brachialis* Fahraeus). Control is difficult because the vetch has escaped from cultivation and is a common weed as well.[37] DDT has been found to give "excellent control." [6, 37] The bruchid is one of the 30 insects against which DDT has been pronounced especially toxic.

Two applications of 3 to 5 per cent pyrophyllite dust at 22 to 25 lb. per acre, one as the pods began to set and the second 15 days later, controlled the pest without injury to the plants. They were also "significantly better" than two applications of a 1 per cent rotenone dust, it was found. In another test, a 3 per cent pyrophyllite dust was applied too late for best results on 5 acres of hairy vetch, but it was commercially profitable nevertheless. The results indicated to the investigators that "one well-timed application of 3 per cent dust at 25 to 35 pounds per acre may give adequate control of the vetch bruchid." The dusts also killed coccinellid beetles, flies, flea beetles, weevils, ants and spiders of various species, and other insects, but few aphids and no syrphids or coccinellid larvae. No dead bees were found nor was there any indication of reduction in the number of live honeybees.

Vetch, like alfalfa, is a crop ordinarily used as cattle feed, even when grown for seed, and comes under the federal warning against such use when it has been sprayed with DDT. It

may be found to be safe enough—other insecticides may present the same difficulty—but further tests as to the amount of residual poison will have to be made before a final verdict is reached.

THRIPS. The majority of the reports so far compiled show that DDT exercises a high killing power over various types of thrips.

In Texas,[10] 20 lb. per acre of 3 per cent dust on cantaloupe cut onion thrips (*Thrips tabaci* Lind.) from 24.6 per leaf on the control plots to 0.9 per leaf on the dusted plants. Two applications of 3 per cent dust at 30 lb. per acre on onions cut thrips 67 per cent in 6 hr., 87 per cent in 72 hr. and 65 per cent in 1 week, but the second application apparently damaged foliage. On onion flower heads the dust cut thrips 85 per cent in 48 hr. and 63 per cent in 96 hr. In Idaho[18] a 5 per cent dust at 25 lb. per acre gave 69 per cent control after four applications, better than a DDT spray (4 lb. 10 per cent dust per 100 gal. per acre) and better than a nicotine spray. But California workers[13] found the 10 per cent dust no better than a nicotine spray, which was surpassed by a DDT spray (6 pt. 10 per cent toluene emulsion to 100 gal. of water).

In another Texas test[2] a 3 per cent dust cut thrips on cotton (*Thrips tabaci* Lind. and *Frankliniella fusca* Hinds) from 84.2 per cent average per plant to 20.1 in 8 hr. and to 25 in 32 hr., applied at 15 lb. per acre. At 20 lb. per acre it cut an infestation of 144.4 per plant to 5.6 in 8 hr. and to 4.7 in 56 hr. It was better than dinitro-o-cyclohexylphenylsulfur. In New Jersey[26] gladiolus thrips (*Taeniothrips simplex* Morison) were controlled with a DDT spray (1 lb. 20 per cent powder per 100 gal. of water), which gave good com-

mercial control equal to standard tartar emetic. A 3 per cent dust every 2 or 3 days was even better.

In Oregon [24] DDT in weak sprays and in 2 or 3 per cent dusts gave a high mortality of pear thrips on prune trees.

A California test [40] used both dusts and sprays on onion thrips, which gave better control than did nicotine sulfate. Because the thrips were destroyed, growth continued much longer in the DDT-sprayed plots with the result that they yielded from 70 to 87 more 100-lb. bags per acre. The tests used 3 per cent dust and 0.1 per cent water suspension with equally good effect.

In another study the DDT sprays and dusts were superior to nicotine sulfate, tartar emetic, nicotine alkaloid, and a mixture of dinitro, nicotine alkaloid, and oil. The DDT emulsion used contained about 0.125 per cent DDT. The workers believed that "further investigations are necessary before this method can be safely recommended for commercial use."

Still another record showed that DDT emulsified in oil to 0.1 per cent was as effective as rotenone against pear thrips larvae, but the oil mixture spotted leaves. Heavy doses of a 0.1 per cent suspension on late greenhouse tomatoes, on which thrips carry spotted wilt, effectively controlled the thrips but apparently stunted the plants and killed lower leaves. The plants, however, still set considerable fruit. They were sprayed four times in 6 weeks with large quantities of the suspension.

Garden Flea Hoppers. Cage tests in Virginia [25] showed DDT in various formulations to be "highly toxic" to the garden flea hopper (*Halticus citri*), both adults and nymphs. Sprays as low as 0.2 lb. per 100 gal. and dusts of 0.4 per cent gave 100 per cent kill in 48 hr. Higher concentrations were

needed in the field—0.4 lb. sprays and 2 per cent dusts—the effects of which lasted as long as 8 weeks. The crop was not named. In Florida [2] a 3 per cent dust gave "excellent control" on celery against *Halticus bracteatus* Say.

Psyllid. Lace Bug. The same Virginia report also recorded a 97 per cent kill in 50 hr. in cage tests with an 0.8 per cent dust against box psyllids on ornamentals and 90 per cent in 72 hr. with a 2 per cent dust against lace bugs (tingids). A Georgia report [9] recorded that a 1 per cent dust gave a high kill of lace bugs on heavily infested ornamentals.

Harlequin Bug. The same Georgia report had a 3 per cent dust effective in the cage but not in the field against the harlequin cabbage bug (*Murgantia histrionica* Hahn) as compared to a rotenone-lethane mixture. A South Carolina record,[8] however, had a 3 per cent dust 100 per cent effective in cage tests on potted kale plants. In North Carolina [14] a 10 per cent dust in cage tests killed 64 per cent in 3 days, while in California [14] a 2.5 per cent dust killed 85 per cent in 5 days. In Louisiana [2] a 10 per cent dust gave up to 100 per cent mortality in 2 days in cage tests, but it was regarded as inconclusive. In Florida [2] a 1 per cent dust killed 90 per cent in 2 days.

Tomato Pinworm. In Ohio [16] a 5 per cent DDT dust and a spray (4 lb. 25 per cent wettable powder per 100 gal. of water) were tested against a cryolite dust and a rotenone spray. Two weeks afterward there were no pinworms on the plants sprayed with DDT, 1 worm per 10 plants on those dusted with DDT, 9.4 per 10 plants on the cryolite group, and 70.6 per 10 plants on the rotenone group. In another test of the DDT spray, plants which had had 11.1 larvae per plant had none at all 3 weeks after being sprayed.

ALFALFA CATERPILLAR. BLISTER BEETLES. A 3 per cent dust in Oklahoma [5] in a laboratory test gave complete control of the alfalfa caterpillar in 18 hr. The laboratory made the same report as to an ash-gray blister beetle and a three-lined blister beetle (*Epicauta lemniscata* Fab.). Other cage tests [2] against the last-named insect showed a high kill from a 3 per cent dust (100 per cent in 3 days) and indicated that the DDT was better than barium fluosilicate.

PEA WEEVIL (*Bruchus pisorum* L.). In Idaho [4, 41] a 5 per cent dust at 30 lb. per acre on peas grown for seed cut the weevil infestation 99 per cent in 2 days, compared to 98 per cent for a 0.75 per cent rotenone dust at 20 lb. per acre, but in all tests the DDT permitted only 2 per cent weevily seed compared to 2.7 per cent for the rotenone.

This report indicated that "contrary to previously published information" DDT promises to be an effective insecticide for pea-weevil control. The 5 per cent dust used was not toxic to the plant, applied to vines at 40 or 80 lb. per acre, nor was a 10 per cent dust when worked into the seed furrow. It seemed to have greater toxicity at 70 deg. Fahrenheit than at 86 deg.

INSECTS ON GUAYULE. A number of insects attacking guayule plants at Salinas, Calif., were found susceptible [42] to control with DDT. They include *Lygus hesperus* Knight, the Western spotted cucumber beetle (*Diabrotica undecimpunctata* Mann.), the false chinch bug (*Nysius Ericae* var. *minutus* Uhler), and larvae of the diamondback moth (*Plutella maculipennis* Curt.). Dusts containing 2.5 and 5 per cent DDT were especially effective against these insects.

The turnip aphid (*Rhopalosiphum pseudobrassicae* Davis), the green-peach aphid (*Myzus persicae Sulz.*), and the pea

aphid (*Macrosiphum pisi* Kltb.) were also controlled, with the kill attaining its maximum, however, only 5 to 7 days after treatment. A 0.3 per cent emulsion spray applied twice was effective against the two-spotted mite (*Tetranychus bimaculatus* Harvey) and proved better than several other insecticides. The immature stages of the Mexican mealy bug (*Phenacoccus gossypii* T. & C.) yielded to the emulsion in 7 days.

STRAWBERRY ROOTWORM. ROSE WEEVIL. Laboratory tests in California [40] both with sprays and dusts showed that DDT kills the strawberry rootworm (*Paria canella* Fab.) and the Fuller rose weevil (*Pantomorus godmani* Crotch). The tests were made by coating glass plates with a 0.125 per cent suspension on which the insects were caged 291 days later. All died in 5 days. A 3 per cent dust, similarly applied, also killed them within 5 days.

PEPPER WEEVIL (*Anthonomus eugenii* Cano). A series of DDT dusts, 10 per cent, 5 per cent, and 2.5 per cent, in California [14] were all better on bell peppers at 15 to 25 lb. per acre at 7-day intervals than 70 per cent cryolite. The 10 per cent and 5 per cent DDT dusts were better at 14-day intervals than the cryolite every 7 days.

COWPEA WEEVIL (*Callosobruchus maculatus* F.). A 3 per cent dust was equal to derris in Florida tests.[2] A leaf-footed bug (*Leptoglossus phyllopus* L.) was similarly controlled on cowpeas in Mississippi.[35]

FALL WEBWORM. In Wisconsin [11] a 3 per cent dust destroyed the nests, all larvae dropping out in 24 hr., while mud-dauber wasps were "very quickly killed" by walking over wire screens treated with a DDT water suspension.

Bean Leaf Beetle. This insect was reported controlled on green and yellow string beans in Kansas [29] by one application of 3 per cent dust. In Minnesota [12] a 5 per cent dust was used to control it. The same report showed the DDT dust more effective than 40 per cent nicotine sulfate spray for the strawberry leaf roller (*Ancylis comptana fragaria*).

Carrot Rust Fly. In Oregon tests [24] a 3 per cent dust gave "highly significant" reduction of injury by this pest; it was applied from a knapsack duster at 0.5 lb. per 100-ft. row. Only 12 per cent of the carrots were wormy compared to 55 per cent in checks.

Symphylids. At Corvallis, Ore., the 3 per cent dust was applied in two ways on beans for this pest.[24] Rototilled into the soil at high rates per acre it was not effective. But when 0.25 lb. of the dust and 5 oz. of bean seeds were mixed and drilled in together, it cut the symphylid population in the soil 97 per cent, reduced root injury, and increased the yield. The same technique with carrot seed permitted only 1.3 per cent injury compared to 11.3 per cent for the next most efficient insecticide and 20.2 per cent for the check rows.

Onion-seed Plant Bug (*Psallus ancorifer* Fieber.). On plants infested at 50 to 75 insects per seed head a 3 per cent dust [24] wiped out all the insects in 48 hr.

Oblique-banded Leaf Roller. A 1.5 per cent dust, a spray (2 lb. of 20 per cent powder per 100 gal.), and a 5 per cent oil emulsion at 2 qt. per 100 gal.—all applied once 2 weeks before blooming—gave 99 per cent control [24] of this insect.

Rice Stinkbug (*Solubea pugnax* F.). A series of tests in Louisiana [86] with 10 per cent dust gave an 88.5 per cent kill in 2 days and 82.4 per cent after 4 days.

Grass Webworm (*Pachyzanela phaeopteralis* Guen.). This lawn-defoliating pest was attacked with a 10 per cent dust at 10 lb. per acre and compared with cryolite and kerosene emulsion.[36] DDT killed all the insects apparently, with neither of the others a close competitor.

Box-elder Bug. Spraying the sides of a heavily infested house with 1 lb. of 20 per cent powder per 100 gal. eliminated this pest for about a week.[26]

A Missouri report[15] concludes in these words:

> The following is a report on preliminary work with DDT against various insects in Missouri. A 3 per cent dust was effective in controlling the following insects: Blister beetle; squash bug up to about half grown (10 per cent DDT controlled adults, but injured the plants); white fly, in greenhouse; thrips on mums; sowbugs on mums; corn earworm, by dusting the silks; Colorado potato beetle; spotted and striped cucumber beetles; northern corn rootworm (adult); pavement ant; lacebugs; leaf hoppers on grape; flea beetles on eggplant. A 10 per cent dust controlled the following insects: Roaches; fleas on dogs, squash bug, adult—injured plants. A DDT spray on apples, used at the rate of 4 pounds of 20 per cent DDT to 100 gallons, controlled leaf hoppers, but did not control San Jose scale on the fruit. DDT dust did not control greenhouse red spider and was not effective against chinch bugs.

Stored-products Insects

Before DDT, a group of a dozen or so insects affecting stored grain had defeated most efforts made against them and run costs of handling grain much higher than they should be. U.S. Department of Agriculture reports indicate that

DDT is "extremely effective" against all these insects, though the possibility of contaminating food supplies must always be kept in mind and excluded from any method of application.

The principal grain insects, against which DDT has proved effective, are the rice weevil (*Sitophilus oryza* L.), the confused flour beetle (*Tribolium confusum* Duv.), the red flour beetle (*Tribolium castaneum* Hbst.), the lesser grain borer (*Rhizopertha dominica* F.), the saw-toothed grain beetle (*Oryzaephilus surinamensis* L.), the Angoumois grain-moth larva (*Sitotroga cerealella* Oliv.), the Indian-meal moth (*Plodia interpunctella* Hbn.), the granary weevil (*Sitophilus granarius* L.), and the cadelle (*Tenebroides mauritanicus* L.). Several other less important pests do not yet appear to have been studied.

One or another of these pests attacks grain in the fields in the South and accompanies it on through harvest, farm, elevator, and mill storage, destroying grain by eating it and causing it to "heat" or to mold, lessening its sales price, and causing handlers to spend substantial sums to clean the material before use. In the North, cold weather destroys many of them, a low moisture content in the grain kills off many more, spraying of bins with lye, kerosene, and other poisons and treating the grain itself with poisonous heavier-than-air gases destroy still more, while modern grain-handling and milling machinery clears them from the material before it goes into products. Some of them cannot penetrate whole grain, but several, such as the rice and granary weevils and cadelle, can go in through the surface of solid grains of corn or wheat, eat out the centers, and use the shells for pupating. Other insects can then clean up the broken grains. They can also penetrate paper or cotton bags. Others feed only on

the surface of kernels. They do not limit their activities to grain but will attack the seeds of almost any plant, such as tomatoes, watermelons, and the like: The Angoumois grain moth, whose larvae bore into and pupate in grain, is the pest most commonly found, but the rice weevil, which lays its eggs in the kernels, is the most destructive. The cadelle is one of the most difficult to combat. Its larvae bore into the woodwork of the granary by thousands, remaining for long periods until the bins are filled. The confused and red flour beetles and the saw-toothed and flat grain beetles are of the group known as "bran bugs."

DDT offers several new and successful methods of attack against these pests.

SEEDS. Since this material is not to be used as food, it can be treated by mixing DDT dust directly with the seeds. In one report [38] the test dosage was 0.05 per cent by weight of technical DDT mixed into the seed. That dosage is high; it would amount to about 16 lb. of 3 per cent dust to each 100 lb. of seed. The conclusion was

> It is evident that treatment of packaged and bulk seed with DDT at the rate of 0.05 per cent by weight will give adequate protection from damage by most insects that infest seed. Dermestid larvae appear to be considerably more resistant to DDT than other insects. Possibly the dense coat of hairs covering the larvae prevents the dust from coming in contact with their bodies. An objectionable feature of DDT as a seed treatment is its inability to repel the insects, but for the most part they are killed before any damage is done. Although no large-scale tests have been conducted with the 3 per cent DDT-pyrophyllite mixture in packaged and bulk seeds, it seems probable that equally good results could be

obtained by using the same dosage of the mixture as of the undiluted DDT.

The tests were conducted on watermelon, corn, tomato, and lettuce seeds in paper envelopes and on sunflower seeds in cotton bags. In each case where the undiluted DDT had been mixed with the seed there was no damage to seed after 2 months' storage, while the control packages were found heavily infested with Indian-meal moth, confused flour beetle, or saw-toothed grain beetle.

In another series of small-scale tests with wheat, grain treated with 0.05 per cent, 0.1 per cent, and 0.2 per cent dosage of DDT was mixed with 100 rice-weevil adults and set aside for 10 days. All the weevils were found dead in all dosages, and there was no emergence of weevils later, indicating that the poison had worked before oviposition could take place. Tests of the germination of the treated wheat showed "no injurious effects," despite the high dosage of 0.2 per cent of undiluted DDT. In still another small-scale test the 3 per cent dust was used at the rate of 15 and 30 parts per million, which also was found "highly effective."

In a U.S. Department of Agriculture statement [39] the following summary of the situation is found:

> DDT has been found extremely effective against most of the common pests of stored seed and its use for that purpose is recommended. It is best used in combination with a carrier dust, to give it greater volume and insure a better distribution over the seed.
>
> If thoroughly mixed with the seed, one ounce of a dust containing 3 per cent of DDT in pyrophyllite or other carrier dust is sufficient for treatment of 100 pounds of seed.

A test made in South Carolina [6] showed that DDT gave complete protection, without affecting germination, in seed corn to which 300 rice weevils were added. The DDT was a 3 per cent dust mixed at the rate of 2 oz. per bushel. Seven months later the treated lot was clear of insects, while the control lots had been badly damaged by the weevils and by Angoumois grain-moth larvae, cadelles, and other insects picked up in the barn in which it was stored.

STORAGE SPACE. DDT, of course, must not be used on grain stored for food because of the possibility of contamination.

However, application of DDT in solution to empty storage space has proved effective against various insects. The report just quoted also says:

> Sprays containing 5 per cent or less of DDT dissolved in refined deodorized kerosene or in water suspension or emulsion have been found very effective and are recommended for use on walls and woodwork of warehouses, flour mills and empty grain bins. The weevils and other insect pests of stored grain and cereal products crawling on or burrowing into the walls or woodwork are killed as they come in contact with the DDT residues.

The Kansas tests referred to above [38] also covered this phase, with special reference to the cadelle. That insect, it is noted, "will cut through almost any type of bag or container," and no fumigant or contact spray yet tried has ever been entirely satisfactory. The tests showed that "the use of a DDT-oil spray may be the best means yet discovered for destroying infestations of these insects persisting in woodwork." In one test where a 6 per cent odorless DDT-kerosene solution was applied to bins of a wooden farm granary, within a few

days "the floors of the bins were littered with large numbers of dead adults and larvae of the cadelle. In one bin approximately 8,000 dead cadelles were swept from the floor at the base of ten linear feet of sprayed wall. The killing action persisted for some time, since dying cadelles were emerging from the walls for weeks after the treatment." In another case a 5 per cent solution cleaned up flour beetles in a wallboard partition of a flour-storage room and gave excellent results against silverfish infestations in a wheat-sample room and the first floor of a flour mill. The residual effect killed invading silverfish for many weeks, the report added.

Since a large part of the infestation of grain by insects is due to insects which hide or breed in cracks and crannies of barns or other storage places, DDT sprays should be directed energetically at such hiding places.

Containers. A final channel of attack on stored-grain insects consists of impregnating with DDT the paper or cotton boxes or bags in which the grain or products are sometimes stored. Several methods have been outlined in U.S. Department of Agriculture reports for accomplishing that end, and all have worked out successfully. One report [6] sums it up thus:

> DDT is one of the most efficient materials yet tested for making paper or fabric bags and cardboard cartons of cereal products immune to insect attack. Paper bags or wrappers that had been immersed in a 10 per cent solution of DDT in acetone or other solvent and dried, apparently gave complete protection of the contents and were not cut through by the cadelle or other species which ordinarily penetrate almost any type of wrapping.

A second method tested was painting one side of the paper container with a varnish containing 10 per cent DDT, and a third was coating one side with a standard clay coating liquor containing 10 per cent DDT. The bags were then filled with flour, tightly sealed and exposed to the cadelle, lesser grain borer, and confused flour beetle. All the treated bags resisted penetration by the insects for many months, while untreated paper was punctured in a few days.

In a small-scale test,[38] common cotton flour bags and No. 5 kraft paper bags such as are used in grocery stores were treated with 5 per cent DDT solution in carbon tetrachloride, one group of each type by spraying the outside, another by dipping. Each bag then received 1 lb. of flour and was tightly closed and placed for 1 month in bins heavily infested with cadelle and confused flour beetles. Tabulated counts of insects found showed that the treated cloth bags had from none to seven flour beetles or larvae and from 4 to 17 cadelles, while untreated checks had 37 adults and 99 larvae of the beetle and 51 cadelles. The treated paper bags showed mostly no beetles or cadelles, while the untreated checks showed 93 adults and 206 larvae of the beetle and 15 cadelles.

The same investigators reported a test on two 100-lb. bags of flour stored in a mill basement. One, dipped in a 5 per cent DDT solution in carbon tetrachloride, was free of insects, the other, untreated, was covered with silverfish.

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Chapter VIII

FOREST, SHADE, AND FRUIT TREE INSECTS

THE value of DDT in controlling insect pests affecting forest and shade trees, ornamentals, and fruit trees has been thoroughly demonstrated, and it is in this group that the earliest recommendations for use of DDT (after mosquitoes and lice) have been made by the U.S. Department of Agriculture. Dosages seem to have emerged more clearly from the profusion of experimental reports, and the trend, as expected, has been to ever lighter doses. In fact most of the records indicate that a spray of 1 lb. of DDT to 100 gal. of water is entirely satisfactory. That is equivalent to 4 lb. of a 25 per cent concentrate or 5 lb. of 20 per cent water-dispersible powder. It makes a 0.1 per cent spray. It has also been noted that sprays are more effective in most cases than dusts.

Most of the work on airplane distribution of DDT has also been done for this group of insects, aside from the antimalaria work of the Army. A number of fairly large-scale tests have been made in forest areas of Pennsylvania against several important insects, all with definite success.

The insects against which the U.S. Department of Agriculture has so far tested the 0.1 per cent spray are [1]

Catalpa sphinx (*Ceratonia catalpae*)
Eastern tent caterpillar (*Malacosoma americana*)
Elm bark beetle (*Scolytus multistriatus*)
Green-striped maple worm (*Anisota rubicunda* F.)
Gypsy moth (*Porthetria dispar* L.)
Japanese beetle (*Popillia japonica* New.)
Mimosa webworm
Pine sawflies (*Diprion simile, D. frutetorum, Neodiprion abietis, N. lecontei* Fitch)
Spruce budworm (*Archips fumiferana* Clem.)

(These are among the 30 insects against which DDT has been shown to be "definitely more effective than those insecticides currently used" and "especially toxic.") Other forest and shade-tree insects for which DDT is recommended are [2]

Boxwood leaf miner (*Monarthropalpus boxi*)
Locust leaf miner (*Cholepus dorsalis*)
Fall cankerworm (*Alsophila pometria* Harr.)
Spring cankerworm (*Palaecrita vernata* Peçk)
Elm leaf beetles (*Galerucella xanthomelaena* Schrank)
Evergreen bagworm (*Thyrodopteryx ephemeraeformis* Haw.)

In addition to the above, the reports indicate that DDT is valuable against "such insects as the tip moths, white pine weevil and the locust borer," but more information is needed.

DDT has been found "very effective" against leaf hoppers (cicadellids); tree hoppers (membracids) and spittle bugs (cercopids), in concentrations of 0.1 to 1.0 per cent. Another

report,[3] detailing studies made especially on insects affecting the elm, says that DDT concentrations as low as 0.125 per cent "effectively kill" those three and many plant hoppers (fulgorids) associated with the elm. When exposure in laboratory tests was as short as 10 min., however, concentrations as high as 2.0 per cent were required to obtained a 100 per cent kill. Sprays of 0.25 per cent DDT emulsions at 2 gal. per 100 sq. ft. applied in late September (the tests were done in Ohio) effectively reduced insect populations on elm, grass, and other herbaceous vegetation for at least 1 month. There was no injury to elm foliage in any test with DDT emulsions.

Adaptation of military technics for airplane dispersion of DDT for insect control has been accomplished successfully in a number of tests, particularly against the gypsy moth,[4] so successfully, in fact, that the work has been extended to a number of other insects.

"Complete control" of the gypsy moth was obtained by application of DDT in oil sprays at the rate of 1 lb. of DDT per gallon of oil, dispersed as a finely atomized mist. The rates of application were from 0.5 lb. per 0.5 gal. per acre to 5 lb. per 5 gal. per acre, with the higher concentrations the more satisfactory. The same technics gave equally good control of the green-striped maple worm, the red-headed pine sawfly, and an imported pine sawfly. A slightly weaker dilution was effective against the spruce budworm.

In a test made near Pittston, Pa., 5 lb. per 5 gal. per acre was dispersed by airplane on the watershed of a small reservoir. Three days later, after 0.75 in. of rain had fallen, the water carried less than 1 part of DDT per 100,000,000 parts of water. A few fish and frogs (which had eaten DDT-killed insects) were found dead, but no birds.

The investigators summed up their work:

> It is believed that the experimental work with DDT in 1944 warrants an optimistic attitude toward its use in the future. Many difficulties must be solved, but it appears that DDT can be used as a spray from aircraft at such low dosages that it will be practical to use it as a control measure against certain forest pests.

The dosages used in the airplane experiments just described were unusually high, amounting to perhaps 12 per cent. In a later publication [2] recommending the use of DDT against the same insects and some others the U.S. Department of Agriculture suggests for limited applications the following typical formula: 1 lb. of technical grade DDT dissolved in 1 qt. of solvent such as xylene, to which is added 1 to 1½ oz. of an emulsifying agent, mixed with 100 gal. of water for a 0.1 per cent emulsion. It adds that the DDT may be cut down to 0.5 lb. per 100 gal. This type of mixture is available commercially in the water-dispersible powders, mixed at 20 per cent or 25 per cent for dilution with water to form whatever strength is desired. For example, 5 lb. of a 20 per cent water-dispersible powder or 4 lb. of a 25 per cent emulsion concentrate would contain 1 lb. of DDT; just add the 100 gal. of water, mix well, and keep it agitated while spraying.

The various mixtures, of course, can be applied from hand or power sprayers with equal success on individual trees or shrubs, as would be the case in a nursery. The U.S. Department of Agriculture report points out that, for the tent caterpillar, it is necessary only to apply the spray to the branches of the wild cherry or other host trees a few days before the eggs hatch or to spray the nests very lightly as they form. For cankerworms, the report continues, since the female

crawls up the tree to deposit her eggs, and for the gypsy moth, since the young crawl up the tree from their hatching places in the soil, control is a matter of spraying the stem of the tree thoroughly for a few feet up from the ground.

Somewhat more powerful concentrations, preferably a full 5 per cent solution or suspension, are also recommended for carpenter ants attacking woodwork or the ambrosia beetles that bore into stored logs and lumber. Floors, baseboards, porches, and similar ant runways should be sprayed, while the beetles are killed if bark surfaces are thoroughly sprayed.

Though some of the reports differ about its effectiveness, the department report recommends a 5 per cent kerosene solution or emulsion in the soil against termites, adding that DDT so used is effective for more than two seasons, all the time it has been tested so far.

The U.S. Department of Agriculture, following tests at its Japanese-beetle laboratory at Moorestown, N.J., called DDT "the best protective agent ever tested against the adult Japanese beetle."[11] It is as valuable applied to foliage for the adult as it is to the soil to kill the larvae.

The Japanese beetle (*Popillia japonica* Newsm.), introduced prior to 1916, has become a serious pest in the Northeastern United States. Starting in New Jersey it spread to Pennsylvania, New York, Connecticut, Delaware, and Maryland in serious proportions, and many scattered local infestations have been reported as far west as Chicago, south to Georgia, and north to Maine. The beetles strip the foliage from thousands of trees and plants from June to September, and the larvae feed on roots through August, September, and October before hibernating and again in April and May before pupating and emerging.

In the New Jersey studies it was found that

> . . . one spray of DDT at the rate of one pound per 100 gallons [of water] applied at or just prior to the beginning of the beetle season gave complete or satisfactory protection to the fruit and foliage of early ripening peaches and apples, blueberries and a miscellaneous group of ornamental and shade trees and shrubs. As many as three applications were necessary to give satisfactory control on grapes on account of the development of new growth during the beetle season. Flowering plants and ornamentals producing blooms and new growth while the beetles are flying will also usually require up to three applications to insure satisfactory protection.
>
> The DDT spray gave excellent control of leaf hoppers on grapes and fair control of the grape berry moth (*Polychrosis viteana* Clem.).
>
> The results with DDT for control of Japanese beetle larvae in soil indicate that this material is more toxic than lead arsenate and that a dosage of 25 pounds per acre, applied either as a dust or spray, will practically eliminate the larval population.

The investigators found that, in 28 various soils, 25 lb. of DDT per acre was more effective than 1,000 lb. of lead arsenate, that it lasted a year, and that it was not modified by fertilizers such as aluminum sulfate, calcium sulfate, ferrous sulfate, tripotassium phosphate, sodium nitrate, sulfur, tannic acid, or lime. Two weeks after the dust was applied to the surface, large numbers of dead and dying larvae were found on the surface, and an intensive survey made in September showed 82 per cent reduction in larval population. "Indications are that none of the surviving larvae will be alive to pupate in the spring," they added. In other plots where 20 lb. per acre of the dust was worked into the top 3 in. of the

soil by cultivation, in May, no living larvae of any sort were found in September. Cutworms were not found, they reported, but "DDT did not seem to have any effect on earthworms."

A number of tests made in New Jersey [12] outlined the value of DDT against the smaller European elm-bark beetle (*Scolytus multistriatus* Marsham), both on cut elm logs and on living trees. Dosages used ranged from 2.5 to 50 g. per liter. The emulsions were effective in preventing attacks on fresh-cut noninfested logs for as long as 69 days and in destroying the insects in wood already infested. On living trees these dosages barred the beetles for 73 days in kerosene solutions and 127 days in emulsions, as measured by the crotch-feeding activity of the beetles.

In elaborate tests at Estes Park, Colo., on the spruce budworm (*Archips fumiferana* Clem.), DDT proved far superior to lead arsenate.[13] In concentrations of 0.05 per cent at a dosage of 2.5 lb. per acre, it brought almost complete mortality of budworm larvae on fir and spruce, with somewhat less effectiveness on ponderosa. Best results were obtained by spraying just before the overwintering larvae left their hiding places.

Fruit Insects

Against this group of insects DDT has not been so uniformly successful, but it has proved effective for most of those against which it has been tested. In the case of the codling moth (*Carpocapsa pomonella* L.), it has turned out to be the best insecticide yet found.

The success against the codling moth, which causes more loss to apple and pear growers in the Pacific Northwest than

any other insect, running up sometimes to more than 50 per cent of the crop, is one of the outstanding achievements of DDT. The damage is done by the larvae, which, as soon as they hatch, crawl to the nearest fruit and burrow into it, spoiling it. They overwinter in cocoons and appear in May or June as moths. These lay eggs that hatch out before July 1 and enter fruit as larvae, remaining for 3 weeks, then spinning cocoons, from most of which moths appear again in July. They produce a second brood of larvae through August. In warmer zones there may be the beginning of a third generation.

Much ingenuity has been applied to the defeat of the codling moth, but never with any great satisfaction. Lead arsenate has been the principal weapon against it, with nicotine in some form also commonly used. In decisive tests DDT worked better than either.

A typical report [5] suggests that 1 or 2 lb. of DDT (5 to 10 lb. of 20 per cent water-dispersible powder) per 100 gal. of water, applied according to the usual schedule for spraying, is the most satisfactory. At Poughkeepsie, for instance, the 2-lb. formulation gave 0.5 worm per 100 apples, against 2.7 for the 1-lb. spray, 9.0 for nicotine bentonite, and 12.3 for the standard lead arsenate. At Yakima, Wash., 0.5 lb. of DDT (2.5 lb. of the 20 per cent powder) per 100 gal. gave 11.4 worms per 100 apples, compared to 14.4 for cryolite, 22.6 for nicotine bentonite, and 16.6 for lead arsenate. It was noted that a combination of 4 oz. of DDT with half the usual concentration of lead arsenate (3 lb.) or nicotine bentonite (1 pt.) per 100 gal. gave even better results, since it did not result in serious increases in mite populations.

By another report,[6] four midseason applications ending July 17, with no sprays afterward, of emulsive summer oil

to give about 2 oz. of DDT per 100 gal., "showed evidence of considerable control efficiency." In a poorly cared for orchard, harvest tallies showed 50.4 per cent moth injury on Jonathans for DDT, compared to 66.47 for lead arsenate imperfectly applied, and 48.63 per cent on Hubbardsons with DDT, compared to 56.65 per cent for the lead-sprayed check. In a well-cared-for orchard, four DDT oil sprays, followed by an oil-nicotine schedule, produced fruit showing only 2 per cent moth injury at harvest, compared with 3.3 per cent for a check plot sprayed with lead arsenate four times followed by the oil-nicotine schedule. There was apparently a "moderate amount of foliage spot-type burn" after the four applications on Delicious, but it did not occur on Jonathan or Hubbardson.

Tests for residues on fruit following these sprays—2 oz. per 100 gal. applied four times—produced 0.004 grain of DDT per pound of harvested Delicious and 0.0045 grain of DDT per pound of harvested Hubbardsons.

APPLE LEAF HOPPERS (*Typhlocyba* spp.). Sprays applied at Yakima [5] for the codling moth also apparently controlled the apple leaf hopper. August 28 the count was 0.6 per 100 leaves on sprayed trees, 25.3 on lead-arsenate-oil-sprayed trees, and 74.3 on those treated with nicotine bentonite. The same observation was made at Vincennes in the codling-moth tests.

GRAPE LEAF HOPPERS (*Erythroneura elegantula* Osb.). The same report said that "promising results" for the control of the grape leaf hopper were obtained in Ohio and in New Jersey with 1.5 lb. of DDT emulsified and suspended in 100 gal. of water.

GRAPE-BERRY MOTH (*Polychrosis viteana Clemens*). Small-scale tests at Sandusky, Ohio,[5] with 1.5 lb. of DDT per 100 gal. showed DDT to be more effective than lead arsenate in

four applications each. In a field test with 1 lb. per 100 gal. on Niagara grapes in New Jersey, 15.6 per cent of the berries were injured in the DDT plot and 41.7 per cent in the lead arsenate plot, though on Jersey Muscat grapes both came out about the same.

ORIENTAL FRUIT MOTH (*Laspeyresia molesta* Busck.). This night-flying moth, best known as a pest of peaches, responded satisfactorily to the 1-lb.-per-100-gal. emulsion, in experiments made in New Jersey. Injury to peaches was "reduced considerably" in field plots so sprayed, it was found. There were two applications, one each just before the appearance of the second- and third-brood larvae. It was noted also that the DDT was toxic to such parasites of the moth as *Macrocentrus ancylivorus* (Roh.)

ROSE CHAFER (*Macrodactylus subspinosus* Fab.). Tests indicate that the same formulation (1.5 lb. per 100 gal.) as was used for the grape-berry moth is destructive of the rose chafer. It is listed by the U.S. Department of Agriculture [2] as one of the important fruit insects susceptible to attack with DDT.

FRUIT-TREE LEAF ROLLER (*Archips argyrospila* Wlk.). Tussock Moth (*Hemerocampa vetusta* Bdv.). The California report [10] told of the successful use of a 0.1 per cent emulsion on apple trees against these two insects.

> Within a short interval after spraying, both species of larvae left the foliage and were hanging by their silken threads. Many dropped to the ground and none were found on the trees 48 hours after spraying, whereas unsprayed trees remained infested. The spray caused a spotted leaf injury.

The same type of oil preparation caused a similar injury on pear trees when used against the tussock moth, and the control was similarly good.

Little Fire Ant. What might be called an "indirect" use of DDT in the fruit-crop field is its recently discovered value against the little fire ant. This is an insect of the citrus groves that does no damage to trees or fruit but attacks the pickers with such vigor that they refuse to work in infested groves. It has been found that spraying the trunks of trees and the ground adjacent with an emulsion of 5 per cent solution of DDT in oil—1 gal. of emulsion to 100 gal. of water—keeps the ants out for nearly a year and permits the pickers to work in peace.

Chrysanthemum Gall Midge (*Diarthronomyia hypogue* Loew.). In a greenhouse where new plants were severely infested [7] it was found that a 0.1 per cent solution (5 lb. 20 per cent wettable powder per 100 gal.) gave good control. On cuttings, 0.64 new gall per plant appeared after spraying, compared with 24.2 on untreated plants, though the larvae and pupae in galls were not affected, and newly emerged adults laid eggs. On newly set plants the control was excellent and no plant injury occurred in 10 weeks.

Asiatic Garden Beetle (*Autoşerica castanea*). The same report showed that the same formulation in badly defoliated chrysanthemums attacked by the night-feeding Asiatic garden beetle would kill 91 per cent of them in a cage test in 2 days.

Walnut Caterpillar (*Datana integerrima* Gr.). In Texas [8] a 3 per cent dust on a heavily infested pecan tree brought a complete cleanup in 2 days. No live insects were found, and there was a thin carpet of dead ones beneath the tree.

Peach Twig Borer (*Anarsia lineatella* Zell.). A spray (2 lb. 20 per cent dust per 100 gal.) of DDT cleared this insect

from an apricot tree, without injury to tree, operator, or consumer.[9]

Filbert Insects.[9] The 3 per cent dust and the same spray at 10 to 12 gal. per tree gave favorable results but were less effective than lead arsenate against the filbert worm (*Melissopus latiferreanus* Wals.). The 3 per cent dust gave practically 100 per cent control of *Cnephasia longana* (Haw.) on new filbert trees.

A U.S. Department of Agriculture summary[5] adds that laboratory and limited field tests indicate that DDT has promise of value against many other insects, including the pistol case-bearer on apple, the annual white grub (*Cyclocephala borealis* Arrow) in the soil, sucking bugs causing distortion of peaches, the hickory shuckworm, the pecan weevil, chestnut weevils, citrus thrips, ants and saw-toothed beetles in stored raisins in California, the grape bud beetle (*Glyptoscelis equamulata* Crotch), and the grape rootworm. It has been promising enough to warrant further tests against the apple maggot, the cherry fruit fly, the pecan case-bearer, and newly hatched crawlers of the Comstock mealy bug.

As was to be expected, DDT has not proved effective against scale insects and orchard mites and is of doubtful value against aphids in forest and orchard. It has not measured up to some previously known insecticides against the plum curculio, the pear psylla, and a few others.

The Home Gardener

Most of the information so far compiled regarding the uses of DDT has had to do with its large-scale employment in the field, the big truck garden, the orchard, greenhouse, or

nursery. The little fellow—the man with a few flowers and a "postage-stamp" vegetable plot in his back yard—would seem to have been neglected. That would be reasonable enough, or at least justifiable, if it were true, in view of the fact that DDT is so new and so important that it was proper to devote the principal early research effort to conquest of insects threatening health or the food supply, especially in wartime. But the neglect is only apparent. Much of the research work, directly or indirectly, has a definite bearing on the insect problem in the small flower, fruit, or vegetable garden, just as the Army's work on flies, mosquitoes, and other domestic pests also benefits the householder and his family.

DDT will kill tomato fruitworms or Japanese beetles or other insects just as effectively in the small garden as it will in the big farm or nursery, and most of the information on it is capable of being translated by any intelligent gardener into terms of his own needs. The following notes should aid him.

The gardener must first realize that DDT is safe enough for him to use. As we have pointed out previously, DDT is a highly toxic substance, as toxic in the laboratory to man and his domestic animals as it is in the field to insects and fish. So are many other insecticides. But in practice the question of dosage lifts DDT almost out of the dangerous class. Even though he took no precautions it would be difficult for the ordinary gardener spraying his chrysanthemums or phlox occasionally to get enough to do himself any appreciable harm; with reasonable care—such as a handkerchief across nose and mouth while spraying—it is practically impossible. Oil solutions should not be left on the skin for any length of time, if spilled, as they can be absorbed through the skin.

However, in the vegetable garden the amount of DDT that may be safely left on fruits to be consumed as food has not yet been definitely determined, as it has been for such poisonous materials as lead arsenate. The rule to follow is not to use it in such a way that a residue of DDT can accumulate on vegetables used as food. For instance, tomato plants should not be sprayed when the tomatoes are ripening, because they are usually eaten without peeling or shucking. The plants can be safely sprayed in the earliest stages of fruiting—and DDT's prolonged action will make that a satisfactory timing—for then the DDT is not on the tomato itself. Again, DDT should not be placed on lettuce, endive, Swiss chard, spinach, and plants used similarly, even though they are washed, for DDT does not dissolve in water, and over a long period enough might remain on the leaves to cause trouble.

On the other hand, it is safe to use it on the tops of such root crops as carrots, radishes, and parsnips, for the edible portion will not be affected. Beets present a different problem. Many housewives cook the tops as greens, and, if that is to be done, DDT should not be sprayed on them, or if it is, the tops should not be eaten; the beets themselves, of course, are safe. In the case of cabbage, it is safe to use DDT, for the outer leaves are not consumed. Another illustrative difference is that between snap beans on one hand and lima beans or peas on the other. The snap beans are eaten pods and all, and no DDT should be applied to them once the pods begin to form. Lima beans and peas are shelled, however, and it is safe to protect them from insects with DDT.

These examples illustrate the interpretation of the rule about the use of DDT on crops. Actually, few experts if any ever expect to see a case of DDT poisoning from intelli-

gent use of it as an insecticide. Despite the tremendous amounts used by the Army and Navy, no case of poisoning has ever been reported by either service. Everything so far learned about DDT points to an extremely wide difference between the dose that is poisonous to insects, an extremely low one, and that poisonous to man, an extremely high one. In that difference lies safety in its insecticidal use.

But, lest someone become careless, it should be kept in mind that it is only "intelligent insecticidal use" that has not caused poisoning. DDT is a poison, after all, and must be carefully handled!

The gardener should be conscious, too, of what has been reported about the adverse effects of DDT in heavy dosages on the gourd family, which includes cucumbers, melons, and squashes of all sorts. Most experts advise against its use on those plants, even though it is a prime killer of the insects associated with them. There is, of course, nothing to bar the use of DDT against the same insects on other plant families.

Otherwise in the vegetable garden and almost entirely in the flower garden, DDT is the answer to the gardener's prayer. It is both a contact and a stomach poison in one, and it can apparently be used on all flowering plants—except ornamental gourds perhaps—for all purposes and in relatively light doses. No reports of injurious effects on any garden plants have yet been received. In fact the only limitation on DDT as the gardener's main reliance is that it has not been found especially effective against mites and scale insects and a few others. *The gardener should remember, however, that DDT will kill bees and should not be applied to open blossoms!* Following that rule will adequately protect the bees and preserve their essential function as pollinators, for bees as a rule do not crawl

on foliage, but light on the blossom, feed, and fly to another.

In selecting a DDT formulation, the gardener should also remember that, while DDT itself is harmless except to the cucurbits, the oil solvents such as kerosene, often used to make solutions of it, will kill foliage. For flower- or vegetable-garden use or for shrubbery and evergreens, these oil solutions should not be employed. Dusts and especially water suspensions or emulsions are just as effective and will not damage foliage. (See chapter on formulations.)

The gardener may use DDT freely, within the lines laid down, and he will find that it is suitable in relatively light concentrations (sprays, 0.1 to 1 or 2 per cent; dusts, 3 to 5 per cent) for most of the insects that trouble him. Assuming that most usage will be by hand sprayer or duster rather than the power equipment of the professional, sprays should be applied until the foliage is thoroughly wetted, but not so wet that the liquid has begun to collect and run off. Dusts should be applied heavily enough to lay a fine film over the foliage of the affected plant. A layer of dust on top of the soil around plants is a valuable method of catching crawling insects en route to them.

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